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Front Cover: Australian Pratincole *Stiltia isabella* at Lambells Lagoon. (Micha V. Jackson)

Back Cover: Freshwater Crocodile *Crocodylus johnstoni*, 3 m male on the bank of the Daly River, September 2011. (Yusuke Fukuda)

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Northern Territory Naturalist (2013) 24: 2–13 Research Article

New locations of butterflies from northern Arnhem Land, Northern Territory

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Abstract

The Northern Territory is a frontier in Australia for biological research in which new discoveries and locations of butterflies are frequently made. In this paper, I report 41 new point locations for 36 species in northern Arnhem Land. In particular, a number of significant range extensions and new spatial records are documented, including new locations for the Copper Jewel *Hypochrysops apelles* and Samphire Blue *Theclinesthes sulpitius* which are more than 500 km from their previous known occurrence in the Northern Territory. Notwithstanding Arnhem Land's remoteness and inaccessibility being key constraints for butterfly surveys, further sampling is recommended to obtain fine-scale distribution data to fill knowledge gaps and to assess the conservation status of particular species. As the majority of the region surveyed is now located within the recently declared Indigenous Protected Area (IPA) managed by Bawinanga Aboriginal Corporation's Djelk Rangers based in Maningrida, these recommendations will assist with the collection of baseline data for future monitoring. A greater focus on this invertebrate group may help to promote the potential use of butterflies as indicators of biodiversity and landscape health.

Introduction

Knowledge of geographical distributions of butterflies in northern Australia, particularly in the Northern Territory, is incomplete (Common & Waterhouse 1981; Dunn & Dunn 1991; Braby 2000). The ease and frequency with which new spatial locations are recorded for a number of butterfly species in the Northern Territory highlights the work to be done in inventory and survey (Miller & Lane 2004; Franklin *et al.* 2005; Franklin *et al.* 2007; Pierce 2008; Dunn 2009). Moreover, Sands and New (2002) recommended that a "coordinated inventory of the incidence and status of all butterfly species in Australia's National Parks and other high level reserves" is needed to assist with future butterfly conservation and management plans.

Braby (2008) acknowledged that although documentation of spatial distribution of Australian butterflies is reasonably good at a very broad scale, there are still substantial gaps, particularly at finer scales. The knowledge base of Northern Territory butterfly fauna, in particular, is very poor and species are conspicuously under-represented, especially in Arnhem Land, when compared with other regions

of the continent (Dunn & Franklin 2010). Not surprisingly, new locations of species outside known ranges in the Northern Territory are frequently reported. Franklin *et al.* (2005) reiterated Braby's (2000) comment that "in many cases, gaps in the ranges shown … do not necessarily reflect natural disjunctions", but represent simple lack of recording.

This paper highlights new locations for 36 butterfly species in northern Arnhem Land. These records extend previously known ranges for these species, with two being of particular significance in that they occur more than 500 km from the next nearest documented location within the Northern Territory.

Methods

The records documented here are based on quantitative sampling of sites as well as incidental observations made between April 2006 and November 2011. The majority of records are from northern Arnhem Land in the vicinity of Maningrida (12°02'S, 134°13'E) situated at the mouth of the Liverpool River. The overall area includes stone country of the Liverpool and Mann rivers in the west, near-coastal regions across the north, and floodplains associated with the Blyth River and Arafura Swamp; Elcho Island formed the eastern boundary. All major habitats were encountered, including mangroves, salt flats, savannah, riparian forest, vine thicket and monsoon forest, as well as settled areas.

Permission was sought from relevant traditional owners to trap and release butterflies using a standard entomological sweep net. On two occasions permission to collect was granted for three hesperiids – a family of butterflies particularly difficult to identify in the field and for which local information has been unavailable. Where a net was not available, species were observed in the field and occasionally photographs were sent to experts to assist with identification. Texts used for identification included Braby (2000) and a field key to the lycaenid butterflies of the Top End and Kimberley (Franklin & Bisa 2008).

Quantitative sampling of sites was employed over a specified, but not necessarily standardised, time frame. Approximately 25–30% of sites were revisited. The spatial area sampled among sites was not standardised, but generally it varied from 50–500 m radius from the point location. Postsampling I applied abundance classes that I had been using to record data during the past 10 years (i.e. 1–2, 3–5, 6–10, 11–50 and >50). These classes were devised for recording abundance data in a Microsoft Access database which I co-constructed and have maintained with the assistance of like-minded butterfly enthusiasts since 2002. For the purposes of this paper these classes have been categorised alphabetically as follows: A = 1–2; B = 3–5; C = 6–10; D = 11–50 and E = >50.

To determine whether my records were new point locations, I compared data with current distribution maps published in Braby (2000) and subsequent papers published in the scientific literature. A hand-held GPS using WGS84 datum was used to determine point locations. Where a GPS was unavailable, coordinates were obtained retrospectively using Google Earth.

Results

I confidently identified 58 species of butterflies from northern Arnhem Land. Of these, 36 species (62%) represent 41 new point locations (Table 1; Figure 1). Geo-coordinates for these 41 new point locations are listed in Appendix 1. Ten of these 36 species were recorded at just a single new location with abundance generally low (A or A–B), except for the Pale Pea-blue *Catochrysops panormus* (A–D) and Jewelled Grass-blue *Freyeria putli* (B–D) (Table 1). The remaining 26 species occurred at two or more new locations with one, the Orange Ringlet *Hypocysta adiante*, recorded at 23 new locations (Table 1).

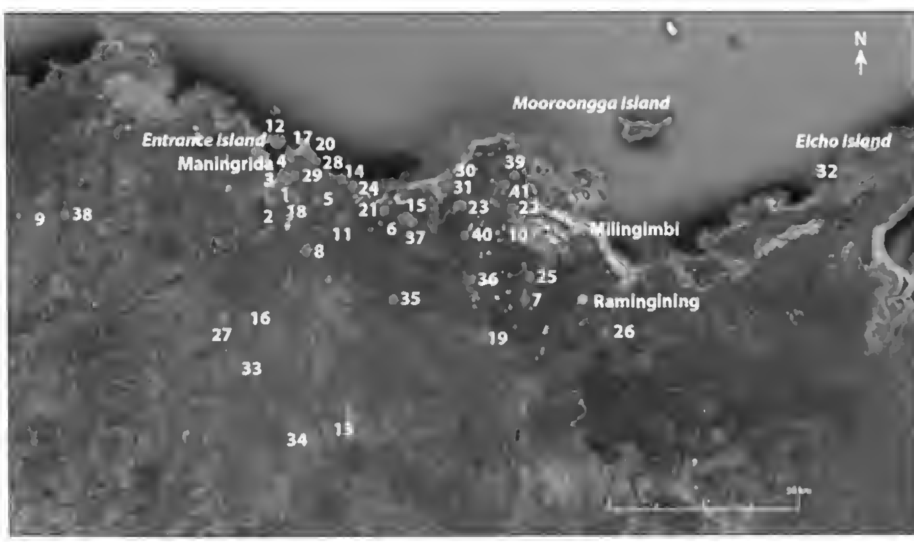


Figure 1. Map of northern Arnhem Land showing area surveyed and new point locations plotted. Adapted from Google Earth (2010).

Table 1. New point locations for 36 species of butterflies from northern Arnhem Land. Numbers refer to locations shown in Figure 1; the coordinates are listed in Appendix 1. Abundance scores refer to the number of adults recorded as follows: A = 1–2; B = 3–5; C = 6–10; D = 11–50; E = >50.

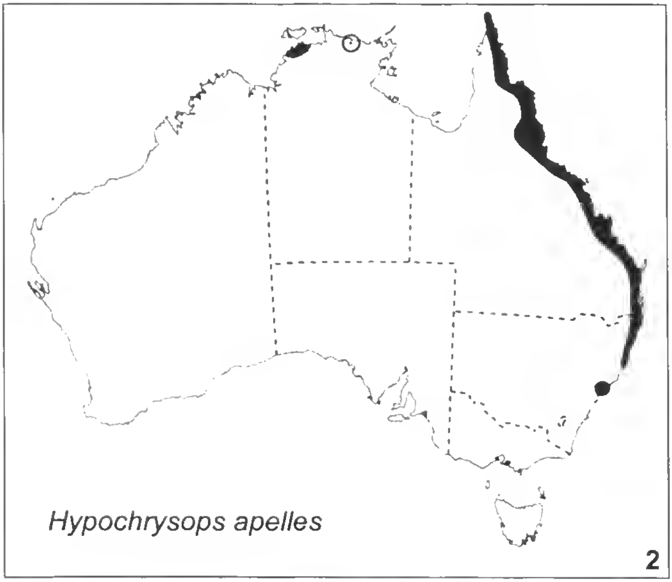
Species	Locations	Abundance
HESPERIIDAE		
Broad-banded Awl *Hasora hurama*	8, 16	A
Chrome Awl *Hasora chromus*	3	A
Sword-brand Grass-skipper *Neohesperilla xiphiphora*	4	A
Lyell's Swift *Pelopidas lyelli*	1, 2, 4, 8, 19, 40	A–B
Narrow-brand Grass-dart *Ocybadistes flavovittatus*	16, 36	A
Yellow Palm-dart *Cephrenes trichopepla*	4, 32	A
PAPILIONIDAE		
Clearwing Swallowtail *Cressida cressida*	1, 4, 18, 20, 22, 32	A–D
Fuscous Swallowtail *Papilio fuscus*	1, 3, 4, 5, 8, 9, 39	A
PIERIDAE		
Small Pearl-white *Elodina walkeri*	4, 12, 17, 32	A
Mangrove Jezebel *Delias aestiva*	1, 2, 3, 14, 23	A–D
NYMPHALIDAE		
Small Brown Crow *Euploea darchia*	15, 17, 21, 30	A–D
Swamp Tiger *Danaus affinis*	1, 2, 3, 4, 5, 6, 8, 9, 11, 14, 15 16, 19, 20, 21, 26, 29, 30	A–D
Orange Lacewing *Cethosia penthesilea*	1, 2, 3, 4, 14, 15, 17, 24, 25, 28, 29	A–C
Chocolate Argus *Junonia hedonia*	2, 4, 5, 7, 9, 13, 15, 16, 19	A–C
Blue-banded Eggfly *Hypolimnas alimena*	2, 8, 9, 13, 15, 27	A–B
Evening Brown *Melanitis leda*	1, 2, 4, 13, 15, 16, 39	A
Dingy Bush-brown *Mycalesis perseus*	2, 4, 13, 16, 19, 21, 36	A–E
Cedar Bush-brown *Mycalesis sirius*	1, 2, 4, 5, 7, 11, 13, 15, 16	A
Orange Ringlet *Hypocysta adiante*	1, 2, 3, 4, 5, 7, 8, 9, 11, 13, 15, 16, 19, 20, 25, 26, 30, 32, 33, 34, 35, 39, 41	A–D
Dusky Knight *Ypthima arctous*	5, 7, 11, 13, 15, 16, 19, 34, 37, 38	A–B

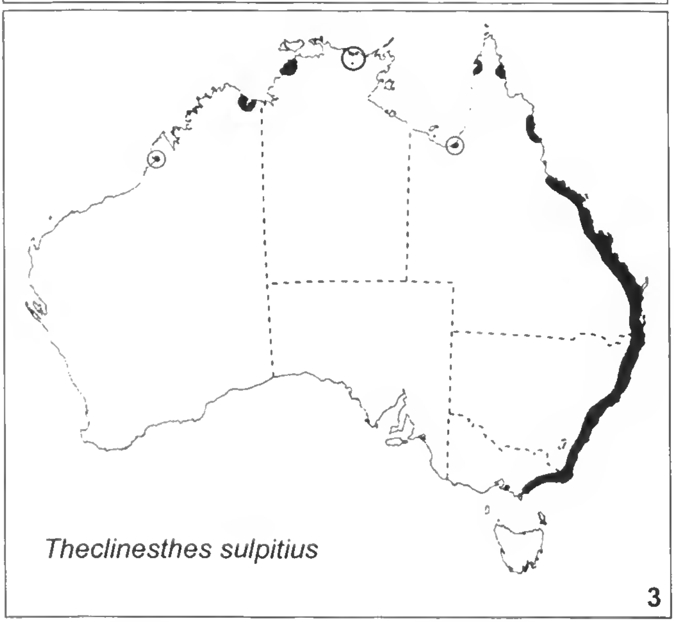
Table 1. Continued.

Species	Locations	Abundance
LYCAENIDAE		
Copper Jewel *Hypochrysops apelles*	2	A–B
Purple Oak-blue *Arhopala eupolis*	1, 2, 3, 8, 9, 13, 15, 16, 19, 27	A–C
Black-spotted Flash *Hypolycaena phorbas*	2, 32, 33	A
Pale Ciliate-blue *Anthene lycaenoides*	2	A
Dark Ciliate-blue *Anthene seltuttus*	3	A
Purple Line-blue *Prosotas dubiosa*	32	A
Speckled Line-blue *Catopyrops florinda*	1	A
Samphire Blue *Theclinesthes sulpitius*	4, 10, 14, 31	A–D
Purple Cerulean *Jamides phaseli*	3, 4, 15, 17, 20, 29	A–B
Pale Pea-blue *Catochrysops panormus*	2	A–D
Spotted Grass-blue *Zizeeria karsandra*	3, 4, 12, 14, 20	A–C
Common Grass-blue *Zizina otis*	1, 4, 7, 20, 32	A–D
Black-spotted Grass-blue *Famegana alsulus*	1, 2, 4, 8, 11, 15, 19, 20, 29, 32, 34, 35	A–D
Dainty Grass-blue *Zizula hylax*	7	A
Spotted Pea-blue *Euchrysops cnejus*	1, 2, 4, 29	A–D
Jewelled Grass-blue *Freyeria putli*	14	B–D

The Copper Jewel *Hypochrysops apelles* (Figure 2) and Samphire Blue *Theclinesthes sulpitius* (Figure 3) were recorded more than 500 km from the only other documented locations in the Northern Territory. The Copper Jewel (Figure 4) was recorded in small numbers from three of seven surveys at location 2 – mangroves fringing the Liverpool River (Figure 6). The Samphire Blue (Figure 5) occurred at locations 4, 10, 14 and 31 where tidal influences and salt pans were evident (Figure 7). This species was encountered in large numbers at times, particularly during August of 2007 and 2009.

Several species uncommonly encountered (Chrome Awl *Hasora chromus*, Broad-banded Awl *Hasora hurama*, Sword-brand Grass-skipper *Neohesperilla xiphiphora*, Narrow-brand Grass-dart *Ocybadistes flavovittatus* and Dainty Grass-blue *Zizula hylax*) also have limited distributions in the Top End (Brahy 2000). The remaining species encountered have broader distribution ranges in the Northern Territory.





Figures 2–3. Distribution maps of lycaenid butterflies with new point locations encircled: **2.** Copper Jewel *Hypochrysops apelles*; **3.** Samphire Blue *Theclinesthes sulpitius*. Adapted from Braby (2000); additional location data for Samphire Blue encircled black from Williams *et al.* (2006) and Pierce (2011).

Figures 4–5. Noteworthy lycaenid butterflies from northern Arnhem Land: **4.** Copper Jewel *Hypochrysops apelles* from location 2, 12 April 2008; **5.** Samphire Blue *Theclinesthes sulpitius* from location 10, 1 July 2007. (D. Bisa)

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Figures 6–7. Butterfly habitat: **6.** For Copper Jewel *Hypochrysops apelles*, location 2; **7.** For Samphire Blue *Theclinesthes sulpitius*, location 14. (D. Bisa)

Discussion

The butterfly fauna of northern Arnhem Land is relatively poorly known, which is reflected in the many new records presented here. The detection of a number of noteworthy spatial records for the Northern Territory is significant, in particular new locations for the Copper Jewel and Samphire Blue. It is expected, however, that these species would occur more broadly in the Northern Territory as their larval food plants and preferred breeding habitats are well represented. For example, mangrove communities are widespread and common, especially along waterway margins and floodplains in Australia's tropical north (Wightman 2006). Specifically, the White-flowered Black Mangrove *Lumnitzera racemosa* identified by Meyer (1996) as the primary larval food plant of the Copper Jewel occurred at location 2, and Braby (2011) recently identified the Smooth-fruited Spur Mangrove *Ceriops australis* as a secondary larval food plant for this species. *Tecticornia* spp. have been identified as common larval food plants of the Samphire Blue (Meyer 1996; Braby 2011). The Grey Samphire *Tecticornia australasica*, and the glassworts *Halosarcia indica* and *H. halocnemoides* often associated with the presence of this species, were prevalent in tidal zones at various sites. It is therefore not surprising that Meyer and Wilson (1995), who first recorded the presence of the Samphire Blue in the Northern Territory, suggested that its range was likely to extend across the coastal regions of the Northern Territory and also into the gulf country of Queensland. Nonetheless, these new locations fill significant gaps in ranges for both these species and highlight the value of field-based surveys.

The presence of most other species reported here could have been predicted based on frequency and abundance records in surveys from similar habitats in the Northern Territory (Franklin & Bisa, unpubl.). Indeed, the ease and frequency with which the majority of northern Arnhem Land species were encountered suggests that with further sampling it is likely that many more new locations will significantly infill the ranges of many species.

Current butterfly distribution maps in the Northern Territory appear as point locations or synoptic interpolations therefrom. Other than Dunn and Dunn (1991), there are no point locality maps and the generalisation of those in Common and Waterhouse (1981) and Braby (2000) tend to obscure the point data, extent of sampling and extent of gaps. Interpolation, however, is reasonable and necessary, particularly in poorly surveyed regions, but it is clear that authors differ in the geographic extent and spatial scale to which they are willing to interpolate. For example, notwithstanding the increase in knowledge over time, Braby (2000) depicted the distribution of the Orange Ringlet in northern Australia more narrowly than did Common and Waterhouse (1981). It is possible that my reports of frequently encountered species will inspire confidence to redefine the geographical distributions of several species.

Although access to northern Arnhem Land can be difficult I recommend that further field research be undertaken in this biologically diverse region. The area is generally restricted to Aboriginal people or those with permits obtained from the Northern Land Council, and seasonal inundation during the monsoon period exacerbates isolation of the region by cutting off large areas. Additional point locations will assist with addressing distributional knowledge gaps and updating current generalised maps for the majority of butterfly fauna in the Northern Territory. Furthermore, as IPAs identified by the Commonwealth of Australia (2011) now encompass much of the region surveyed in this study, additional knowledge has the potential to assist with conservation and management plans under the umbrella of the National Reserve System. New (2010) also identified the importance of encouraging community ownership of conservation initiatives, of which establishing baseline data is deemed vital. Consequently, there now appears to be increased potential for conservation and land management agencies to engage local communities in raising the awareness of the value in establishing baseline data and monitoring biodiversity, including butterflies. Moreover, in relation to assessing the conservation status of butterfly fauna, Sands and New (2002) emphasised the need for identifying and managing threatening processes, several of which are particularly applicable to Arnhem Land (e.g. inappropriate fire regimes, adverse impacts of weeds, buffalo and pigs). Therefore, engaging wide-ranging support, including local Indigenous participation, to conduct further surveys will be essential. The potential benefits in Arnhem Land for all land managers and future generations could be immense.

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Appendix

Appendix 1. Geo-coordinates (latitude, longitude) for 41 new point locations in northern Arnhem Land from which butterflies were sampled.

Location	Latitude	Longitude	Location	Latitude	Longitude
1	12°03'18"S	134°13'53"E	**22**	12°06'38"S	134°46'46"E
2	12°05'46"S	134°11'30"E	**23**	12°06'23"S	134°39'35"E
3	12°03'02"S	134°13'26"E	**24**	12°03'28"S	134°23'53"E
4	12°02'48"S	134°13'31"E	**25**	12°16'36"S	134°49'02"E
5	12°05'36"S	134°18'26"E	**26**	12°24'09"S	135°00'37"E
6	12°08'30"S	134°30'45"E	**27**	12°22'00"S	134°05'00"E
7	12°19'11"S	134°48'33"E	**28**	12°00'27"S	134°18'17"E
8	12°12'41"S	134°17'02"E	**29**	12°02'31"S	134°15'15"E
9	12°08'01"S	133°40'25"E	**30**	12°02'32"S	134°37'20"E
10	12°08'21"S	134°47'20"E	**31**	12°04'05"S	134°37'10"E
11	12°08'07"S	134°22'01"E	**32**	12°01'17"S	135°34'19"E
12	11°57'32"S	134°12'38"E	**33**	12°28'59"S	134°06'58"E
13	12°37'06"S	134°19'23"E	**34**	12°38'56"S	134°17'59"E
14	12°02'55"S	134°21'55"E	**35**	12°19'33"S	134°30'05"E
15	12°07'59"S	134°31'28"E	**36**	12°16'20"S	134°40'49"E
16	12°21'39"S	134°07'54"E	**37**	12°08'38"S	134°31'35"E
17	11°59'02"S	134°17'06"E	**38**	12°07'27"S	133°41'28"E
18	12°05'15"S	134°15'17"E	**39**	12°02'04"S	134°47'26"E
19	12°24'52"S	134°41'54"E	**40**	12°10'13"S	134°39'39"E
20	11°59'37"S	134°17'40"E	**41**	12°03'34"S	134°45'46"E
21	12°07'28"S	134°28'05"E			

Standardised method of spotlight surveys for crocodiles in the tidal rivers of the Northern Territory, Australia

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Abstract

Standardised spotlight survey procedures have been an integral part of long-term (1975-2012) monitoring programs for Saltwater Crocodiles *Crocodylus porosus* and Freshwater Crocodiles *C. johnstoni* in tidal rivers of the Northern Territory (NT) of Australia. These programs, implemented four years after depleted Saltwater Crocodile populations were protected from hunting in 1971, have been instrumental in documenting post-protection population recovery and evaluating management interventions. This article describes a standardised method for spotlight survey of crocodiles in tidal rivers, with particular emphasis on practical aspects that were not previously documented. It also shows example survey data and how it is analysed. This practical guide is primarily oriented at maintaining survey standardisation within the NT, but it should help wildlife managers to use standardised spotlight counting as a monitoring tool for crocodilian species in similar habitats elsewhere.

Introduction

The Northern Territory (NT) of Australia has a long history of monitoring its crocodile populations (Messel *et al.* 1981; Webb *et al.* 2000; Fukuda *et al.* 2011). The University of Sydney, in collaboration with the NT Government, initiated the first surveys in 1971 and implemented a standardised spotlight surveying program in tidal rivers in 1975 (Messel *et al.* 1981). Retaining this standardised methodology within the monitoring program has contributed significantly to the confidence with which survey results can be used to assess management interventions and anticipate future changes in the population (Webb *et al.* 2000; Leach *et al.* 2009; Fukuda *et al.* 2011).

Two species of crocodile occur in the coastal wetlands of the NT, the Saltwater Crocodile *Crocodylus porosus* and the endemic Australian Freshwater Crocodile *C. johnstoni*. Both were depleted historically due to uncontrolled hunting for skins. Saltwater crocodiles were hunted for 26 years (1945–71) before being protected (Webb *et al.* 1984) and were critically depleted by 1971, whereas Australian Freshwater Crocodiles were hunted intensively for only five years (1959–64) before protection. Saltwater crocodiles were historically abundant in tidal rivers and other coastal floodplain wetlands, whereas the majority of the Australian Freshwater Crocodile population was upstream in non-tidal rivers and billabongs.

Survey programs started in 1971, using a variety of methods (spotlight counts, aerial counts, track surveys, boat sightings) to locate remnant Saltwater Crocodile populations. Standardised spotlight surveys commenced in 1975 to monitor population trends as the recovery started (Messel *et al.* 1981; Webb *et al.* 1984; Webb *et al.* 2000). The subsequent recovery in abundance and biomass has been well documented (Webb *et al.* 1984; Fukuda *et al.* 2011) and the wild population now supports sustainable harvest programs (Webb & Manolis 1993; Leach *et al.* 2009). This has only been possible because the long-term monitoring program, with standardised survey methods, has provided unequivocal evidence of the changing status of Saltwater Crocodiles over time and the effects of management interventions. Although Australian Freshwater Crocodiles were not the primary target of the monitoring programs within tidal rivers, it soon became apparent that they too were found in this habitat. Spotlight surveys could therefore provide indices of temporal change in abundance, population size structure and distribution of this species.

The survey method applied in the NT from 1975 onward was originally described by Messel *et al.* (1981) and extended by Bayliss (1987). Since then, some components have been adjusted to take advantage of new technologies. The current NT survey program includes a suite of practical considerations, learned through experience, that have not previously been documented despite their obvious value for those undertaking surveys.

The central aim of this paper is to provide a concise, updated and practical guide for standardised spotlight surveying of crocodiles in NT tidal rivers, based on 37 years of experience. If this method is applied to populations of Saltwater Crocodiles or other crocodilian species in similar habitats elsewhere, it should enable their changing status to be monitored prospectively. Recovery of diminished populations could be compared directly with recovery of Saltwater Crocodiles in the NT (Fukuda *et al.* 2011). The survey method is also applicable to non-tidal rivers, billabongs and lakes with an open water surface, although each habitat type may have different visibility biases.

Survey Methods

Environmental context

As described by Messel *et al.* (1981), the tidal rivers of the NT fall into a number of different categories depending, in part, on whether they meander across floodplains or are drowned river valleys. All contain saline water at the mouth, but during the annual dry season (April/May to November) a salt wedge moves progressively upstream. Depending on the volume of freshwater flowing into the upper reaches the dry season salinity profile may decrease with distance upstream, or increase due to evaporation if the input of freshwater is limited. The tidal sections of NT rivers are typically lined with mangroves and floodplain grasses and sedges. Most tidal rivers in the NT have two tidal cycles per day with an average of approximately 5 m between the heights of high and low tides. Annual average rainfall is around 1400 mm, but 95% of this falls within a discrete wet season (November to April/May). Increased water flow during the wet season restricts upstream progression of tidal influence in most rivers. During the dry season, water inundates the mangroves on high tides and exposes mud banks with limited vegetation at low tide. The dry season, in which little rain falls, can be broadly subdivided into a cool period (May to August), during which crocodiles bask, and a hot period (September to November) when they avoid heat, reducing the chance of them being seen.

Initial survey

When surveying a river for the first time, a preliminary survey at low tide during the day should be conducted to check river conditions, such as access to a boat ramp, location of barriers (rocks, sand bars and logs), water depth and travelling time to the starting point of survey, so that the nocturnal spotlight survey can be done safely. If long-term monitoring is planned, results of this preliminary survey will help design the survey strategy for that river. Given that crocodile densities vary within and between rivers (Fukuda *et al.* 2007; Fukuda *et al.* 2011), separate survey sections, with different start and finish points, may not be equivalent in terms of distance or crocodile abundance. For example, surveying the same distance in different rivers may require different amounts of time and effort. Each survey section should be reasonably expected to be surveyed in one night (see below).

Survey planning

The start and end points of each section must be exactly the same between years, because crocodile abundance and distribution along a river varies over time and space (Fukuda *et al.* 2007; Y. Fukuda, unpubl.),. In addition, the effect of seasonal changes in temperature and water level that affect crocodile behaviour (Webb 1991) must be minimised. Hence repeated surveys over years should be conducted in the same month, ideally within the same two-week period. The exact date and time of a survey will depend on the tide. Surveys are conducted during a low tide at night,

usually in mid to late dry season (winter). In the coldest period of the dry season, when water temperatures are higher than air temperatures, most crocodiles are in the water at night where they can be spotted at low tide (Hutton & Woolhouse 1989; Webb 1991). During warmer periods of the dry season, a higher proportion of crocodiles remains on the bank amongst vegetation or buried in mud, sites where there are lower probabilities of sighting them. Superimposed on this variation is movement of crocodiles from temporary water bodies (e.g. floodplains and billabongs) into the river mainstream as the dry season progresses. This is in part moderated by the extent and timing of the previous wet season rains (Webb 1991), which affect water levels in these temporary water bodies. Detection probabilities in riverine situations also increase with decreasing water depth (Fujisaki *et al.* 2011).

Surveys should proceed from downstream (the river mouth) to upstream (inland), with the survey boat staying ahead of the incoming tide. This maximises the duration of water levels around low tide suitable for conducting surveys. Hence daily tide tables and the timing of tidal delays up rivers need to be assessed carefully. Maximum exposure of bare river banks without vegetation which shields crocodile eyes from the spotlight occurs at low tide. Spring tides are preferable to neap tides because they expose more of the bank for longer periods. Around 1–2 hours on either side of low tide is normally suitable for surveying at any one site, so surveys should start at the downstream limit of the section on a falling tide, around 2 hours before low tide.

The maximum survey time and distance covered (moving upstream) will largely be determined by crocodile density and speed of survey. In tidal rivers with medium to high densities of crocodiles (>5 eye-shines detected per kilometre), average speed of progress along a river is between 8 and 10 km/h, allowing 40 km to be surveyed in 4-6 hours. Spring low tide progresses upstream at approximately 20 km/h in the tidal portion of many rivers in the NT. Thus, by commencing 2 hours before the time of low tide, the low tide will reach the boat's position slightly after the halfway point is reached. Surveys should only start earlier than 2 hours before low tide at the start point if the water level is already well below the level of the fringing vegetation. Likewise, if the incoming tide raises the water level to cover exposed mud banks earlier than expected, surveys should cease. A long river (>50 km) may need to be subdivided into defined sections that can be surveyed on consecutive nights.

If the river width exceeds about 400 m, each side should be surveyed separately (e.g. midstream-west bank and midstream-east bank). Tributaries (side creeks) should be surveyed separately from the mainstream; additional time should be allocated to allow for time needed to travel in and out of each tributary. Survey sections in the same river, particularly adjacent sections, should ideally be surveyed

on consecutive nights, to reduce the possibility of crocodiles moving between sections. All the sections should be surveyed in the same direction (from downstream to upstream).

A detailed schedule, along with a large-scaled map of each section such as those prepared by Messel *et al.* (1982) for the tidal rivers in the NT, and a projected survey timetable, should be developed for each river. For longer rivers with multiple survey segments, one or more extra nights should be scheduled to allow unexpected delays. Access to a boat ramp, travelling distance, and time to the start and end point of survey section should be included in the schedule. A typical spotlight survey requires a minimum of three people (boat driver, spotter and data recorder) as described below. A full checklist of equipment required for a spotlight survey (Table 1) will help ensure that surveys do not need to be abandoned because some critical element was forgotten.

Safety procedures

Physical conditions during a survey can be difficult. A survey, including travelling to the start point, typically takes 8-12 hours. Personnel may be exposed to very hot conditions on the water during the day and cold conditions (including wind chill) at night, which means appropriate protective clothing is essential. The spotlight may attract large amount of insects, and mangroves often contain mosquitoes and biting midges ('sandflies'). In some situations protective glasses may be needed, and use of effective insect repellent improves comfort and reduces the risk of acquiring insect-borne disease. A break of 10 minutes every 90 minutes is good practice as it allows the team members to retain concentration during a survey. Sufficient food and water should be taken on each trip (see Table 1 for quantities).

To be prepared for emergencies, a first aid kit, satellite phone, emergency flare, distress radio beacon (e.g. marine Emergency Position Indicating Radio Beacon (EPIRB)), life jackets and repair tool kit must be present on all survey boats. All team members should be trained in first aid. Although direct contact with crocodiles during a spotlight survey is highly unlikely, one team member with an appropriate qualification should carry a compact firearm. The boat should be equipped with oars, ropes, spare propeller and sufficient fuel. Oars are important for escaping from shallow water where the engine cannot be used. Development of a safety protocol specifically formulated for a spotlight survey, including a communication plan (e.g. contacts for emergency), is highly recommended.

Boats and boat driving

A survey boat needs to be large enough to accommodate at least three people and the survey gear, but also small enough to operate at low tide in shallow and/or narrow streams. A 4.5 m aluminium dinghy with a 30 horse power (hp) engine should be used

Table 1. List of survey equipment typically required for three people for one run of a spotlight survey (survey distance <50 km).

Item	Quantity
Batteries (D, C, AA, AAA)	12 each
Battery (12 V, 100 A)	1
Emergency flare	1
EPIRB	1
Fire arm	1
First aid kit	1
Food and water	9 snacks and 9 L
Fuel	25 L
Gloves	4 pairs
Goggles	4
Hand held GPS	1
Head lights	4
Insect repellent	3
Life jackets	4
Light globes	3
Maps	3
Note books and pens	2 each
Oars	2
Paper data sheets	10
PDA cables and cases	3 each
PDAs	3
Propellers	3
Protective clothes	3
Rain coats	3
Repair tool kit	1
Ropes	3
Satellite phone	1
Spotlights (100 W)	2
Sun screen	1
Waterproof torch	1

for most crocodile surveys (Figure 1), although 5-6 m boats powered by 50-60 hp engines can be used in large rivers. The boat should be equipped with adequate fuel and carry all necessary safety equipment (see Table 1). The boat driver should have adequate experience and may be required by government regulation to hold an appropriate qualification (e.g. Coxswain certificate). Boat drivers should be familiar with techniques used in crocodile spotlight surveys as described below.

Travelling speed during a survey largely depends on the condition of the river (water depth, crocodile density, visibility through vegetation, etc), but 15-25 km/h appears ideal for most tidal rivers in the NT. A hand-held spotlight (Figure 2) is used to detect eye-shine. Given the time taken to approach and record crocodiles sighted, surveys should proceed at 8 to 10 km/h if there is a medium to high density of crocodiles (>5 eye-shines per kilometre). Total distance travelled during a survey, taking into account the approaches to crocodiles, is around 1.5 to 2.5 times the linear river length. The boat should not go faster than 30 km/h even in a very low density site, because eye-shine is noticeably more difficult to detect at higher speed. The boat should slow down as each crocodile is spotted and approach the animal as closely as possible for species identification and size estimation. Boat speed should be reduced gradually to minimise any bow wave or sudden change in engine noise likely to increase the probability of the crocodile fleeing and submerging. We recommend an approach speed of 5-10 km/h within 50 m of a crocodile. The boat should stay on the midstream line of a river when searching for eye-shine (Figure 3). If an eye-shine is spotted on a bank, the boat should slow down and approach the crocodile at right angles to the edge of the water. The boat should return to the midstream for the next eye-shine (Figure 3). Even if multiple eye-shines are recognised along one bank in relatively close proximity (e.g. 50 m), the boat should not remain close to the bank in moving from one crocodile to the next, because crocodiles are less likely to move off if approached at a right angle from the midstream line. The wave from a boat approaching slowly parallel to the bank is more likely to disturb animals in the most common location, at the edge in shallow water. The boat driver needs to pay constant attention to signals from the spotter (Figures 4–8) as well as to the environment (e.g. water depth, currents, logs and trees in the water).

Spotlighting crocodiles

Crocodiles are spotted using a hand-held spotlight (Figure 2), of at least 100W (200 000 candlepower), powered by a lead-acid battery (12 V, 100 Ah). For narrow creeks and billabongs, light intensity may need to be lowered for better spotting crocodiles. The spotter stands at the bow of the boat with the spotlight held near eye level. Spotters should scan the water surface, water edges, banks and vegetation with the light, in a zigzag manner from one side of the river to the other, of searching for the eye-shine of a crocodile. An eye-shine of a crocodile glows pink,

red or orange in the light (Figure 9) and is often visible from a long distance (more than 300 m) in clear conditions. Since visibility of eye-shine is greatly reduced in smoke, fog, mist or rain, surveys should not be carried out in these conditions. Other animals such as Barramundi (*Lates calcarifer*), Water Buffaloes (*Bubalus bubalis*), feral Cats (*Felis catus*) and wallabies also reflect eye-shine in the spotlight, but these animals can be easily distinguished from a crocodile with some experience, because they have different colours in the eye-shine. If spotters move the light too slowly, or fix the light on a crocodile in the distance and cease searching the banks as it is approached, the probability of missing potentially visible crocodiles will increase.

Signals for effective communication between the spotter and boat driver are important (Figures 7–11). The spotter is responsible not simply for locating crocodiles, but for directing the boat driver around obstacles that are not visible to the driver (e.g. submerged logs, rocks and sand bars), and for directing the approach to observed crocodiles.

When a crocodile eye-shine is recognised the boat should continue to move upstream, in midstream, while the spotter ensures no other crocodiles are being missed on either side. The spotter then directs the boat towards the spotted crocodile, with the aim of a close approach to ascertain crocodile species and size. Approaching from midstream at near right angles to the crocodile maximises the chance of getting a clear view of the crocodile before it moves away. The spotlight beam should be directed on or immediately above the eye-shine as the boat approaches, because this seems to discourage the crocodile from moving off.

Figures 1–2. Equipment used for crocodile survey: **1.** Boat with a 30 hp engine; **2.** Spotlight (100 W) connected to a battery (12 V, 100 A);

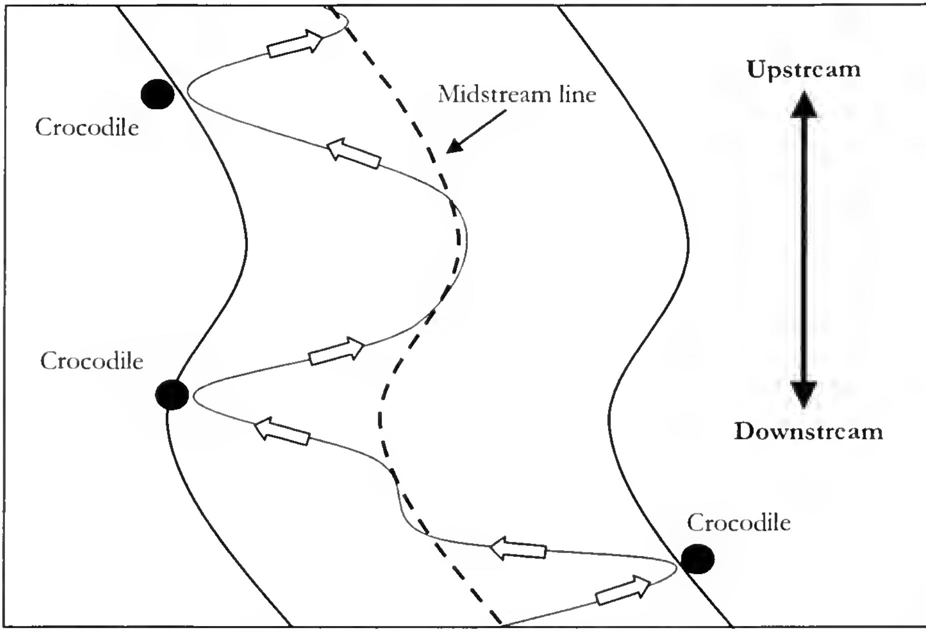
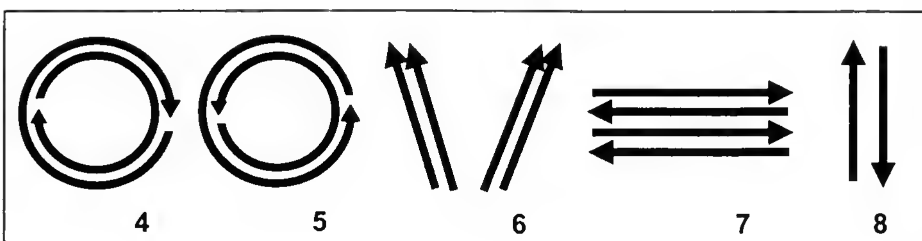


Figure 3. Track of survey boat during a nocturnal spotlight crocodile survey. Solid lines indicate river banks. The boat should move upstream and stay on the midstream line (large dashed line) and approach each crocodile from the midstream line. In a wide river, the boat should remain at least 10 m from the water's edge when running parallel to the bank.



Figures 4–8. Spotlight signals used to communicate to the boat driver during a spotlight survey of crocodiles: **4.** Clockwise circles indicate "go faster"; **5.** Anticlockwise circles indicate "go slower"; **6.** Up to the left/right indicates "go left/right"; **7.** From side to side indicates "stop the boat"; **8.** One flip up and down indicates "one crocodile in the direction of an eye-shine". All signals should be shown clearly in the front, high enough to be obvious to the driver.

Total length (TL) of a crocodile refers to the distance from the tip of the snout to the tip of the tail and is usually estimated using 0.3 m (=1 ft) intervals. Crocodile size usually ranges from 0.3 to 5.4 m (1 to 18 ft) for Saltwater Crocodiles and 0.3 to 3.6 m (1 to 12 ft) for Freshwater Crocodiles. Saltwater crocodiles smaller than 0.6 m (2 ft) and Freshwater Crocodiles smaller than 0.3 m (1 ft) are often recorded as "hatchlings of the year". In most cases only the crocodile's head and anterior neck are visible in the water, and spotters need to estimate size from this portion. In Freshwater Crocodiles, and in Saltwater Crocodiles between 1.2 and 4.2 m long, TL is around 7 times head length (HL) (Webb & Manolis 1989; Fukuda *et al.* 2013). The HL/TL ratio increases with body size and a 1:8 ratio should be used for large Saltwater Crocodiles (>4.2 m) (Fukuda *et al.* 2013). As a general guide, the head of large crocodiles can take on a very "bulky" appearance; the head of a 5 m crocodile appears to have twice the physical bulk of the head of a crocodile with a TL only 1 m shorter. The HL/TL ratio should be used only as a guide. Experienced spotters rely on their familiarity with the variable appearance of crocodiles of different sizes and estimate TL from head and neck size rather than mere HL. In general, spotters who are involved in capturing crocodiles make more accurate TL estimates.

Figure 9. Eye-shine of a saltwater crocodile in a spotlight. An eye-shine usually glows in bright red in the light and may be visible from a distance (approximately 300 m) in clear conditions.

Observer bias in the ability to detect eye-shine is generally small, but is higher for estimating TL, both within and between individual spotters (Choquenot & Webb 1987; Webb *et al.* 1989). It is essential that the spotlighter has sufficient training at estimating TL before they conduct surveys.

If a crocodile submerges before its size is estimated, it is recorded as "eyes only" and no estimate of TL is recorded. In some rivers, Freshwater Crocodiles and Saltwater Crocodiles co-inhabit at high densities. Accurate identification of species, particularly for small crocodiles, requires some experience. Freshwater crocodiles have narrower snouts with post-occipital scales behind the cranial platform and a lower proportion of the head is occupied by the cranium (although this is not evident in smaller animals). Saltwater crocodiles have raised wider cranial platforms and rarely have post-occipital scales behind the cranial platform (Richardson *et al.* 2002).

The position of crocodiles located within the river is recorded in one of six categories, defined by Messel *et al.* (1981): midstream (MS), shallow water on edge (SWOE), on mud (OM), in mud (IM), in vegetation (IV) and in vegetation in water (IVIW).

Data recording and navigation

The spotter's determination of species, TL and position (e.g. *C. porosus*, 6-7 ft, MS) is called out to the data recorder who sits adjacent to or behind the spotter in the boat. Although data can be recorded manually on paper (Figure 10), electronic data entry using a Personal Digital Assistant (PDA) or palmtop computers (Figure 11–13) has some technical advantages for efficiency. The PDA should contain a Global Positioning System (GPS) that records a complete track of the survey run and a data recording program that records the detail of each crocodile observed during the survey (Figure 14). Other than the continuous survey track, the GPS records the coordinates of the boat when it approaches each crocodile eye-shine as closely as possible. The data recording program should be able to accommodate all the elements of each observation (date, time, species, TL, position and GPS location). Such data recording programs can be developed with a desktop computer and installed on a PDA using software such as CyberTracker (CyberTracker Conservation 2012) or NS Basic (NS BASIC Corporation 2012). Paper datasheets should be available on the boat in case of technical failure of the PDA.

The data recorder is responsible for navigation using detailed topographic maps (1:50 000 and 1:100 000) in both paper and electronic form. They should be familiar with the survey area and any boat hazards it presents, and should record general information pertaining to each survey such as date, weather conditions, coordinates and time at the start and end points, and names and roles of the survey members.

Crocodile Spotlight Survey

Location: ______________________________

Date: ________________

Spotter: ________________

Recorder: ________________

Boat driver: ________________

Start point: ______________________________

Finish point: ______________________________

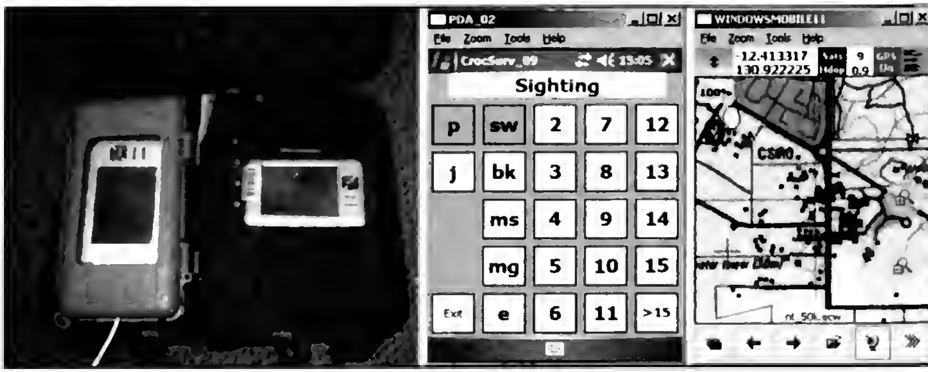
Start time: ________________

Finish time: ________________

Notes:

#	Species	Size	Position	GPS	Notes
1					
2					
	As many rows as practical				
25					

Figure 10. Front page of a paper datasheet previously used to record crocodile observation data. Electronic data recording on a PDA is now preferred and provides more efficient spatial data capture for GIS, but paper datasheets are available as backup (the full data sheet can be downloaded from Appendix A of the supplementary material).



11 12 13

Figures 11–13. Electronic data entry: **11.** Personal Digital Assistants (PDAs) for data recording and navigation; **12–13.** Two screenshots of PDA: **12.** Crocodile data recording screen; **13.** GPS mapping program.

Species	Size	Position	Date	Time	Latitude	Longitude
C. porosus	6-7	SOWE	06/07/11	19:23:23	-12.66718	131.3344
C. porosus	5-6	SOWE	06/07/11	19:24:18	-12.66893	131.3329
C. porosus	11-12	IV	06/07/11	19:25:59	-12.66872	131.3338
C. porosus	2-3	SOWE	06/07/11	19:27:38	-12.6706	131.3324
C. porosus	6-7	SOWE	06/07/11	19:27:52	-12.67099	131.3323
C. porosus	12-13	SOWE	06/07/11	19:28:38	-12.67234	131.3331
eyeshine	0	IV	06/07/11	19:29:16	-12.67235	131.3331
C. porosus	11-12	SOWE	06/07/11	19:30:08	-12.67326	131.3331
eyeshine	0	IV	06/07/11	19:30:35	-12.67399	131.3331
C. porosus	8-9	SOWE	06/07/11	19:31:05	-12.67471	131.3321
C. porosus	13-14	IV	06/07/11	19:32:24	-12.67506	131.3329
eyeshine	0	MS	06/07/11	19:32:48	-12.67548	131.3328
C. porosus	12-13	SOWE	06/07/11	19:33:35	-12.67668	131.3335
eyeshine	0	SOWE	06/07/11	19:34:22	-12.67789	131.3345
C. porosus	12-13	SOWE	06/07/11	19:34:42	-12.67833	131.3347
C. porosus	4-5	SOWE	06/07/11	19:36:39	-12.68222	131.3345
eyeshine	0	IV	06/07/11	19:36:57	-12.68196	131.3345
eyeshine	0	MS	06/07/11	19:37:50	-12.68305	131.3332

Figure 14. Raw data output of crocodile sighting data extracted from a data recording program (e.g. CyberTracker or NS Basic) in a PDA. These data can be presented on a map (Figure 16) or used to calculate the density and population structure of crocodiles (Tables 2–3).

For navigating the boat, Geographic Information System (GIS) or navigating programs for a PDA such as ArcPad (esri 2012) or OziExplorer (Des & Lorraine Newman 2012) are useful because they have functions to show the real-time location of the observer and record the track of a survey run. The use of two PDAs in a survey, one dedicated to data recording and another for mapping navigation (Figure 11), is recommended. PDAs should be protected in a waterproof case

(or a sealable, transparent plastic bag) against water splash and potential rain. They should be powered by the external battery used for the spotlight. One battery (12 V 100 A) lasts 6-8 hours in continuous use under the load of one spotlight and two PDAs. All data are downloaded to a desktop computer for analysis at the end of a survey (see below).

Data analysis

Spotlight count data are usually collected and analysed to answer questions about changes in abundance and population size structure over time (Webb *et al.* 1984; Webb *et al.* 2000; Fukuda *et al.* 2011). Raw survey data can be imported into a GIS (Figure 15) and used for spatial analyses, such as mapping changes in crocodile distribution or assessing their dependency on habitat quality (e.g. Fukuda *et al.* 2007).

Relative density indices of abundance (the number of non-hatchling crocodiles sighted per kilometre of river surveyed) and biomass (kg of non-hatchling crocodiles sighted per kilometre of river surveyed) are typically calculated and compared to historical data (see example data in Tables 2–3 and Figures 16–17). Hatchlings (0.6 m or <2 ft) should not be included in these indices because of the high variance in both nesting abundance and hatchling success between years (Messel et al. 1981;

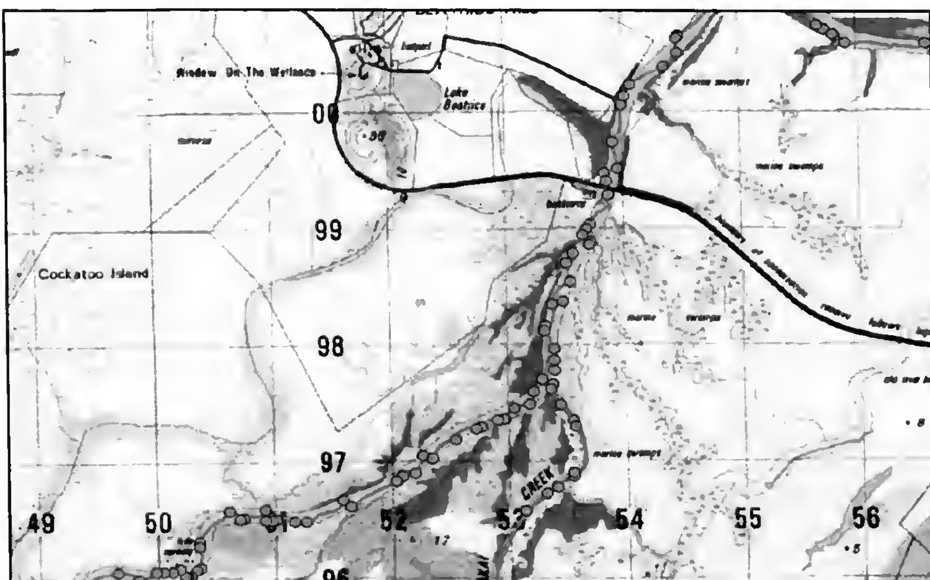


Figure 15. Example of crocodile spotlight survey locations (yellow dots) and the track of the survey run (red line) mapped in a GIS.

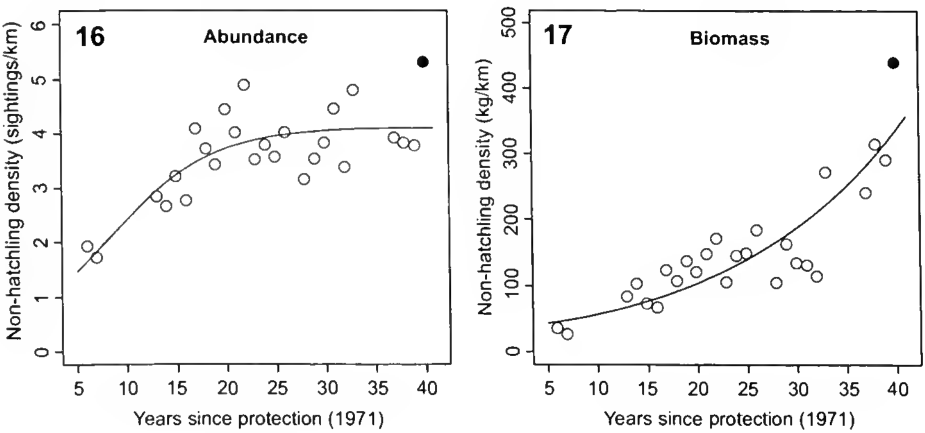
Fukuda *et al.* 2011). The distance of each survey should be measured on an accurate map, or by use of a GIS at an adequate scale (e.g. 1:50 000), along the midline of the river/stream rather than along the actual track taken by the boat. Estimating absolute abundance (e.g. crocodiles present in a river surveyed) from spotlight counts is often not practical because correction factors, even if derived from mark-recapture studies, are error prone and highly variable among rivers and years (Bayliss *et al.* 1986; Hutton & Woolhouse 1989).

Table 2. Example of survey data records from a river (140.74 km) in the NT, showing the number of crocodiles in each size class.

Crocodile size class (ft)	Example values for number of crocodiles	Crocodile size class (ft)	Example values for number of crocodiles
< 2	26	10-11	64
2-3	38	11-12	49
3-4	44	12-13	26
4-5	44	13-14	9
5-6	33	14-15	6
6-7	56	15-16	1
7-8	54	16-17	3
8-9	58	> 17	0
9-10	80	Eyes only	181

Table 3. Population abundance indices calculated from spotlight survey data (excluding hatchlings (< 2 ft) (Table 2). The calculation method for each size class, total number and biomass of crocodiles, and the relative density of crocodiles in abundance and biomass is provided in Webb and Messel (1978) and Fukuda *et al.* (2011). These indices are commonly compared to the historical data in graphs (e.g. Figures 16–17).

Population abundance indices	Example values
Total number of individuals	746
Density	5.30
Total biomass (kg)	61813.71
Biomass density	439.20



Figures 16–17. Examples of graphed crocodile density, present (closed symbol) compared with historical values (open symbols): **16.** Abundance; **17.** Biomass. The line is a fitted trend of the population change. The method for fitting a trend is described by Fukuda *et al.* (2011).

Discussion

The monitoring program for crocodiles in the tidal rivers of the NT has provided important information about the recovery of the wild population after protection (Messel *et al.* 1981; Fukuda *et al.* 2011). Data obtained were instrumental to the decision to transfer the Australian population of Saltwater Crocodiles from Appendix I to Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora' (CITES) (Webb *et al.* 1984). The survey program is an integral part of the safeguards and transparency built into the NT's formal management programs, approved separately at Territory and Commonwealth levels every five years (Leach *et al.* 2009; Delaney *et al.* 2010). Compliance with CITES requires ongoing demonstration that the export of skins is "not detrimental" to the survival of the species; the ongoing spotlight survey program meets this requirement and will be continued in order to monitor the sustainability of harvesting (Leach *et al.* 2009).

Various approaches have been attempted to minimise visibility biases and thus improve survey precision (Messel *et al.* 1981; Bayliss 1987; Choquenot & Webb 1987; Webb *et al.* 1989; Webb *et al.* 2000; Stiratt *et al.* 2001). Our description of the current monitoring program details an effective, successful, standardised survey method. We provide guidance on the logistics of these spotlight surveys, in the hope that this will improve monitoring efficiency and reproducibility.

The standardised monitoring procedures described and recommended here include resources that may not be readily available in other international contexts within which crocodile spotlight surveys are conducted, many of which are in developing countries. Thus the methodology may not be directly transferable and some aspects may need to be modified (e.g. using paper datasheets instead of a PDA for data recording). However, similar logistic constraints and visibility biases are likely to be encountered and may be addressed as described above. As shown in the NT and elsewhere, standardised spotlight surveying is a useful tool for monitoring wild crocodilian populations over the long term (Messel *et al.* 1981; Hutton & Woolhouse 1989; Webb *et al.* 2000; Fujisaki *et al.* 2011; Fukuda *et al.* 2011).

The status of crocodilians, and other wildlife, is essentially a relative measure that requires information on current abundance and/or distribution to be compared to historical or future reference points (Webb 1986). Historical data derived from standardised surveys provide the necessary stable baselines. Maintaining the current survey program, using the same methods, is clearly important for on-going management of crocodiles in the NT. If the program needs to be adapted in future, we would urge that any such adaptation is calibrated against the historical data to ensure that future survey results remain directly comparable with those collected historically.

Acknowledgements

Professor H. Messel at the University of Sydney initiated the monitoring surveys of crocodiles in Australia. After the pioneering work reported in Messel's Monographs in the 1970s and 1980s, Wildlife Management International Pty Limited conducted extensive surveys and analysed results in the 1980s and 1990s. The Northern Territory Government and Parks Australia (Kakadu National Park) maintain the current monitoring programs for crocodiles in the NT. Nearly 40 years of monitoring effort has been made possible through assistance from hundreds of people from different organisations, including traditional owners of the rivers and lands in the NT. A. Fisher, G. Edwards, B. Crase, S. Casanova, N. Trikojus and B. Lukitsch provided helpful comments on the manuscript.

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Habitat associations of birds at Manton Dam, Northern Territory

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Abstract

Manton Dam is an impoundment of the Manton River approximately 50 km south-south-east of Darwin, Northern Territory. Major habitats associated with the dam (open water, water edge, riparian monsoon forest and savanna woodland) were searched to determine the bird species associated with each. A total of 84 avifauna species were recorded. Diversity (22 species) and abundance of waterbirds were low in comparison with other wetlands of northern Australia—only 11 bird species were recorded using the open water habitat. The paucity of waterbirds may be due to the lack of shallow foraging areas. Bushbirds included 50 species that used riparian monsoon forest habitat and 45 species that used savanna habitat; 34 species were recorded in both habitats. Nine waterbird species were also recorded using riparian monsoon forest habitat. Further development of riparian vegetation around the fringes of the dam may encourage colonisation by additional forest bird species. Increasing the extent of shallow water areas and prohibition of motorboats may enhance habitat availability and quality for waterbirds and shorebirds.

Introduction

Habitats for birds depend on the local geology, landforms, vegetation communities, and the presence and distribution of water. In the monsoon tropics, the distribution of vegetation communities is largely determined by position in the landscape, duration of inundation and availability of soil moisture (Taylor & Dunlop 1985; Bowman & Minchin 1987; Wilson & Bowman 1987; Cowie *et al.* 2000). Habitat development is a natural process that involves changes to the structural diversity and boundaries of vegetation over time. Vegetation patterns of the tropical savannas are particularly influenced by fire, soil moisture and longer term climatic and sea-level changes (Bowman & Minchin 1987; Bowman 1992; Williams 1994, 2001; Woinarski *et al.* 2004; Banfai & Bowman 2005). Land clearance for agriculture and housing, alteration of waterways by damming and other means, and the introduction of invasive species (weeds and feral animals) may also dramatically modify important habitats for birds.

Birds use habitats with varying degrees of specificity, influenced by vegetation structure, floristics, fire regime, and availability of resources including food,

water, cover and nesting sites such as trees, hollows, cliffs, etc. (Recher 1969; Rowley 1975; Rotenberry 1985; Franklin & Noske 1999; Noske & Franklin 1999; Woinarski 1990). Bird habitats in the Top End have been variously defined in relation to recognised vegetation communities (Crawford 1972; Morton & Brennan 1991; Woinarski *et al.* 1988, 2000; Goodfellow 2005; Reynolds 2010).

At Manton Dam, the Manton River (a tributary of the Adelaide River) has been blocked by the dam wall at a point where it once flowed through a gorge. An area that previously comprised a seasonal watercourse surrounded by savanna has been replaced by an extensive and permanent waterbody. Consequently, over the past 70 years, wetland and rainforest plants have colonised the riparian fringe. Other dam schemes in northern Australia, for example Lake Kununurra, Lake Argyle, Darwin River Dam, Fogg Dam, Lake Bennett and Lake Moondarra (Mt. Isa), have similarly resulted in changes to fringing vegetation (ANCA 1996).

Wetlands in the seasonally dry Top End support a distinct range of waterbirds and other avifauna species (Sedgwick 1946; Crawford 1979; Bamford 1990; Morton & Brennan 1991; Press *et al.* 1995; Cowie *et al.* 2000). Manton Dam provides habitat for waterbirds and is one of the few large, open, deep water bodies in the region. The establishment of riparian habitat around the fringes of the dam has been accompanied by the appearance of birds more associated with forested habitats. These riparian zones support a relatively high diversity of species, and birds are often more abundant in these zones (Woinarski *et al.* 2000). In this paper, I document the birds of Manton Dam and describe their habitat associations.

Methods

Study area

Manton Dam (12°50'S, 131°07E) is situated approximately 50 km south-south-east of Darwin (*c.* 70 km by road), Northern Territory (Figure 1). It was constructed during the Second World War and completed in 1942. Manton Dam was Darwin's first reliable water supply but was superseded in 1972 by the larger Darwin River Dam (Cramp 2005). Prior to its opening as a recreation area in 1989 the dam was drained and many tree stumps were removed (Boland 1995). Nowadays it is primarily used for recreational fishing and skiing (DIPE 2002). The surface area of the water occupies 360 ha, and the Manton Dam Recreation Area (NT Portion 3837) covers 11,600 ha (Boland 1995; DIPE 2002). Average depth is *c.* 4 m and the deepest point (near the dam wall) is *c.* 14 m when the dam is full (Boland 1995). The dam overflows in most years and there is drawdown of 1 to 1.5 m due to evaporation in the dry season (Townsend 1997), exposing the wetland fringe, with the lowest levels in November or December prior to the wet season monsoon rains (Townsend 1997).

Manton Dam provides some shallow, gently-shelving habitats restricted to the upper reaches where wet season creeks flow into the dam. Dead trees in these areas,

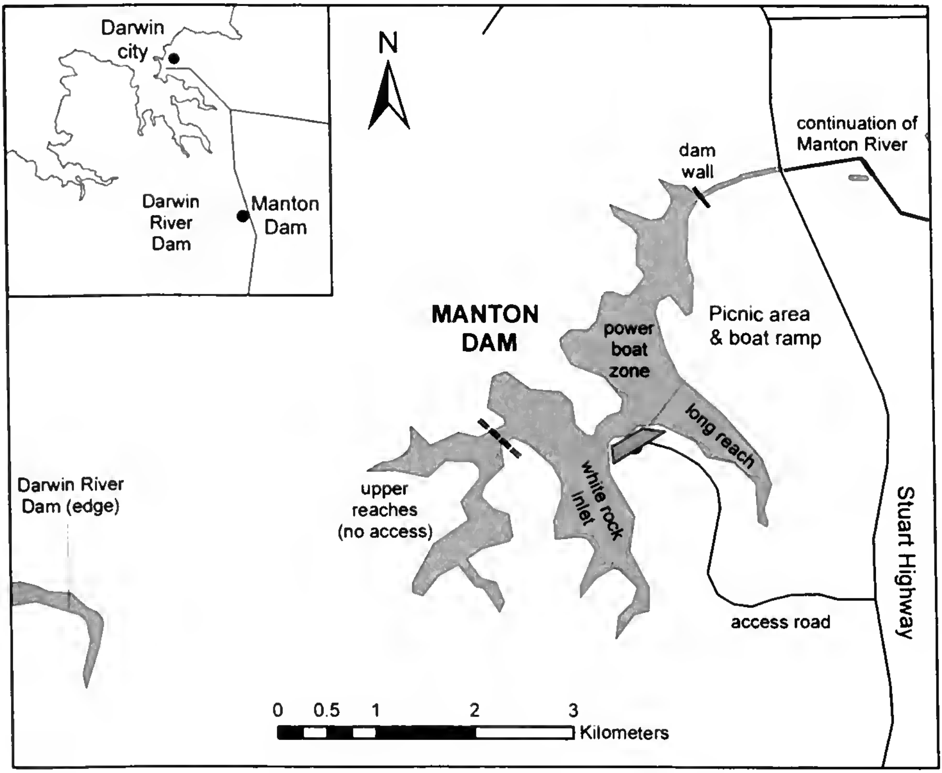

Figure 1. Map of Manton Dam and surrounding area, Northern Territory.

including long reach, provide important roosts for waterbirds, with little disturbance by motor boats. Fishers and skiers tend to restrict their activities to the main body of open water between the boat ramp and the dam wall (Figure 1).

Water temperatures are coolest between June and August (22-25°C) and warmest in December and March (31-32°C) (Townsend *et al.* 1997). Thermal stratification (warmer water at the top) occurs regularly and is particularly noticeable between August and December when there is no inflow (Townsend 1997).

Habitats

The main habitats associated with the dam include the open water (OW) of the dam proper, the water edge (WE) which includes the shallow margins and embayments (to 2-3 m depth) of the main waterbody, the riparian monsoon forest (RF) including a rainforest patch, and savanna woodland (SW) (Figures 2–3). Trees, shrubs and some

of the aquatic plants of the area were identified using Wightman and Andrews (1989), Brock (1993), Dunlop *et al.* (1995) and Cowie *et al.* (2000); older names have been updated where necessary.

Open water

The majority of OW habitat is deep and therefore not vegetated, although it covers many stumps of dead trees in peripheral areas. Much of the main body of the dam comprises OW habitat.

Water edge

In shallower water (WE habitat) sub-surface aquatic plants occur extensively, and include *Ceratophyllum* sp., *Hydrilla* sp. and *Myriophyllum* spp. (Townsend 1997). Emergent and surface aquatic plants occur only in WE habitat and include *Persicaria attenuata*, water lilies *Nymphaea violacea* and *Nymphoides indica,* and Spike Rush *Eleocharis sundaica* (Figure 2). The muddy fringes of the dam become exposed in the dry season and there is widespread evidence of damage by pigs in these areas.

Riparian monsoon forest

The riparian habitat (RF) varies considerably in extent and in areas with steep slopes it is only 2–3 m wide. This habitat supports *Pandanus spiralis,* River Pandanus *Pandanus aquaticus, Melaleuca* spp., patches of *Lophostemon lactifluus* and sporadic Leichhardt Trees *Nauclea orientalis.* In embayments along minor drainages and in other seasonally inundated areas, low *Melaleuca* forests of Silver-leaved Paperbark *M. argentea* and Weeping Paperbark *M. leucadendra* have developed (Figure 2); these communities have higher tree densities, higher litter cover and lower grass cover than surrounding savannas (Bowman 1992). Bases of the trunks of paperbarks (*Melaleuca* sp.) around the edge of the dam are partially submerged during the wet season and many have developed aerial roots.

Adjacent to the picnic area is a patch of closed rainforest (included in RF habitat) which supports approximately 30 species of trees and shrubs (only the more common or obvious species are listed here). The overstorey is dominated by Black Wattle *Acacia auriculiformis,* Freshwater Mangrove *Barringtonia acutangula,* Leichhardt Tree *Nauclea orientalis* and *Carallia brachiata.* In the small tree layer *Timonius timon, Cyclophyllum schultzii, Breynia cernua, Exocarpos latifolius* and the palm *Livistona benthamii* are common. Vines and climbers include Fountain Bush *Opilia amentacea,* Supplejack *Flagellaria indica, Smilax australis* and Snake Vine *Tinospora smilacina.* Banyan *Ficus virens* and Weeping Fig *F. benjamina* occur patchily and shade out or strangle other trees. *Canarium australianum* is common but occurs primarily as saplings. Species that are escapees or plantings include *F. benjamina,* White Cheesewood *Alstonia scholaris* and Mango *Mangifera indica.* Grassed parts of the picnic area are mown regularly, and watering by sprinklers at night provides a potential source of drinking water for some birds.

Figure 2. Habitats at Manton Dam: open water habitat in the foreground, and fringing water edge habitat with water lilies and rushes; in the background, seasonally inundated riparian (*Melaleuca*) monsoon forest. (S. Reynolds)

Savanna woodland

Savanna woodland (SW habitat) exists on the stony low hills surrounding the dam (Figure 3). Common tree species are Ironwood *Erythrophleum chlorostachys*, several species of eucalypts (*Corymbia polysciada*, *Eucalyptus tectifica* and Stringybark *E. tetrodonta*), Billy Goat Plum *Terminalia ferdinandiana*, *Owenia vernicosa*, Cocky Apple *Planchonia careya*, Cycad *Cycas armstrongii* and Sand Palm *Livistona humilis*. Turkey Bush *Calytrix exstipulata* and Kapok Bush *Cochlospermum fraseri* occur in patches. The presence and abundance of native savanna plants is influenced by regular dry season burning (Russell-Smith *et al.* 2010; Bond *et al.* 2012), as is the widespread occurrence of the invasive weeds Mission Grass *Pennisetum poystachion* and *Hyptis suaveolans*. Wild Passion Fruit *Passiflora foetida* was also common. Large boulders and stony ridges provide protection from fire in the savanna matrix (Fensham 2012) and these sites support additional species including *Pouteria sericea*, Banyan *Ficus virens* and *Denhamia obscura*.

Figure 3. Example of savanna woodland habitat on stony ground in the dry season. The area includes a stand of the Sand Palm *Livistona humilis* and a eucalypt overstorey. (S. Reynolds)

Avifauna Surveys

During surveys for Merten's Water Monitor *Varanus mertensi* at Manton Dam in April 2005, I made opportunistic observations on the bird life of the area. The dam was visited on four occasions during this period for approximately 12 h on each day (from sunrise to sunset). Survey methods involved aural and visual surveys of the waterbody (OW and WE habitats) and fringing vegetation (RF habitat) as I travelled around the fringes of the dam and as far as the dam wall by boat (Figure 1). The surveys also incorporated areas in the upper reaches of the dam that are not usually accessible by boat (Figure 1). Surveys by boat were made in the early morning, in the late afternoon, and occasionally at other times of the day. The remainder of the time was spent in the picnic area (located at 12°51'44"S, 131°07'15"E) and its immediate surrounds (generally within 300 m of the boat ramp) where observational surveys were made on foot, and aural surveys were conducted by sitting in one place and recording all species heard (and seen) for periods of 30-60 minutes.

The dam was revisited for two days in August 2010 (for approx. 12 h, from sunrise to sunset) and a further day in late September 2011 during which I surveyed the waterways by kayak and the picnic area and access road on foot. The surveys by kayak focused on long reach and white rock inlet (Figure 1). Thus, the total number of survey days during the study was seven.

Observations were mainly undertaken during periods of partially cloudy, warm (28-33°C) and moderately humid weather. All bird species within each habitat were recorded. Species not immediately distinguishable by eye were identified with the aid of binoculars. Birds flying overhead were assigned to the habitat in which they were foraging (e.g. Whistling Kite, White-bellied Sea-Eagle, Tree Martin) or passing through (e.g. Varied Lorikeet). Egrets and other waterbirds passing over OW and SW habitats while travelling to roosting or foraging areas were not included, but a waterbird was considered to be using OW habitat if it was swimming in (e.g. cormorants) or on (e.g. Green Pygmy-goose) the water.

Avifauna nomenclature and family sequence follows Christidis and Boles (2008). Several taxa considered to be full species by Schodde and Mason (1999) are listed as subspecies.

Results

A total of 84 species was recorded across all habitats during the survey at Manton Dam (Table 1). The Australasian Darter, Whistling Kite and 17 of the bushbirds were recorded on all seven survey days. In contrast, Pink-eared Duck, Black Bittern, Black Falcon, Brolga, Tawny Frogmouth, Azure Kingfisher and Dusky Honeyeater were recorded only once. Magpie Goose was the most abundant waterbird species (maximum count 180) and Wandering Whistling-Duck (maximum count 120) was the second most abundant. The resident Green Pygmy-goose was the third most abundant waterbird species, occurring in OW habitat and amongst floating aquatic vegetation in WE habitat. Counts of all other waterbird species were fewer than 25 individuals (Table 1).

Habitats

Open water

A total of 11 species was observed using OW habitat, comprising eight species of waterbird (Table 1), two species of raptor (White-bellied Sea-Eagle and Whistling Kite) and Tree Martin (Table 1). With the exception of Green Pygmy-goose, Little Pied Cormorant and Little Black Cormorant, waterhirds occurred in low numbers. Cormorants and Australasian Darter were recorded during all surveys. Two Pink-eared Ducks were also recorded in OW habitat (Table 1).

Water edge

A total of 24 species was recorded in WE habitat, comprising 18 species of waterbird (Table 1), two species of raptor (White-bellied Sea-Eagle and Whistling Kite), Masked Lapwing, Azure Kingfisher, White-breasted Woodswallow and Tree Martin. Most waterbirds were observed foraging along the shore or in water less than 0.5 m deep. Egrets used the shallow water amongst reeds, whereas Radjah Shelduck occupied wet grassy edges. In September, towards the end of the dry season, waterbird numbers increased, and counts of cormorants, Wandering Whistling-Duck, Intermediate Egret and Comb-crested Jacana peaked at long reach. A solitary Common Greenshank was the only migratory shorebird observed.

Riparian monsoon forest

Avifaunal species richness was highest in RF habitat (59 species). Nine species of waterbird (Table 1) were observed in RF habitat, usually encountered in the fringing *Melaleuca* forest. Forest Kingfisher was found in and adjacent to the rainforest patch, where I located a nest in an arboreal termitarium some 12 m above the ground. Most fruit-eating birds, such as Pied Imperial-Pigeon, Australasian Figbird and orioles, occurred exclusively in this habitat. Sulphur-crested Cockatoo was usually recorded in RF habitat, but also occurred in SW habitat. Rainbow Lorikeet was attracted to paperbark blossom in RF habitat, but also fed on eucalypt (*Eucalyptus* spp. and *Corymbia* spp.) blossom in SW habitat. Owls were only recorded in RF habitat; one or more Barking Owls were heard regularly in the early evening calling from near the boat ramp. Northern Fantail was mainly encountered in RF habitat, but it also occurred on the fringes of SW habitat.

Savanna woodland

Fewer species were recorded in SW habitat than in RF habitat. Eleven species were found exclusively in SW habitat, including Black Falcon, Black-tailed Treecreeper, Weebill, Red-backed Fairy-wren and Rufous Whistler (Table 1). Except for Rufous-banded Honeyeater, which was only recorded in RF habitat, seven out of eight species of honeyeaters recorded during this study occurred in SW habitat and White-throated Honeyeater was only recorded from SW habitat. No species of waterbird were recorded using this habitat (Table 1).

Thirty-four species that occurred in RF habitat were also recorded in SW habitat (Table 1). Red-winged Parrot was mostly observed in SW habitat, and only sometimes in RF habitat. Leaden Flycatcher occurred in both habitats. Blue-winged Kookaburra was common in RF and SW areas and Brown Goshawk was also observed several times using RF and SW habitat.

Table 1. Bird species recorded in various habitats at Manton Dam. Frequency (F) is the number of survey days (maximum 7) for which each species was recorded. Count (C) is the maximum number of waterbirds observed. Habitat categories are as follows: OW = open water, WE = water edge, RF = riparian monsoon forest, SW = savanna woodland.

Species	F	C	OW	WE	RF	SW
Brown Quail *Coturnix ypsilophora*	1				x	x
Magpie Goose *Anseranas semipalmata*	2	180	x	x	x	
Pink-eared Duck *Malacorhynchus membranaceus*	1	2	x			
Green Pygmy-goose *Nettapus pulchellus*	6	100	x	x		
Radjah Shelduck *Tadorna radjah*	2	3		x	x	
Wandering Whistling-Duck *Dendrocygna arcuata*	2	120		x	x	
Australasian Grebe *Tachybaptus novaehollandiae*	1	1	x			
Australasian Darter *Anhinga melanogaster*	7	6	x	x		
Little Pied Cormorant *Microcarbo melanoleucos*	6	18	x	x		
Little Black Cormorant *Phalacrocorax sulcirostris*	5	24	x	x		
White-necked Heron *Ardea pacifica*	1	1		x		
Pied Heron *Ardea picata*	1	6		x		
Black Bittern *Ixobrychus flavicollis*	1	1		x	x	
Eastern Great Egret *Ardea modesta*	1	2		x		
Intermediate Egret *Ardea intermedia*	3	5		x		
Cattle Egret *Ardea ibis*	2	15		x	x	
Australian White Ibis *Threskiornis molucca*	2	4		x	x	
Straw-necked Ibis *Threskiornis spinicollis*	2	5		x	x	
Black-necked Stork *Ephippiorhynchus asiaticus*	3	2		x	x	
White-bellied Sea-Eagle *Haliaeetus leucogaster*	3		x	x	x	
Whistling Kite *Haliastur sphenurus*	7		x	x	x	x
Black Kite *Milvus migrans*	2				x	x
Brown Goshawk *Accipiter fasciatus*	3				x	x
Black Falcon *Falco subniger*	1					x
Brolga *Grus rubicunda*	1	2			x	
Greenshank *Tringa nebularia*	1	1		x		
Masked Lapwing *Vanellus miles*	3			x	x	

Table 1. Continued.

Species	F	C	OW	WE	RF	SW
Comb-crested Jacana *Irediparra gallinacea*	2	16		x		
Bush Stone-curlew *Esacus magnirostris*	2				x	x
Whiskered Tern *Chlidonias hybridus*	1	2	x			
Emerald Dove *Chalcophaps indica*	2				x	
Pied Imperial-Pigeon *Ducula bicolor*	3				x	
Bar-shouldered Dove *Geopelia humeralis*	7				x	x
Peaceful Dove *Geopelia striata*	7				x	x
Sulphur-crested Cockatoo *Cacatua galerita*	7				x	x
Red-tailed Black Cockatoo *Calyptorhynchus banksii*	3					x
Red-winged Parrot *Aprosmictus erythropterus*	7				x	x
Varied Lorikeet *Psitteuteles versicolor*	6					x
Rainbow Lorikeet *Trichoglossus haematodus rubritorquis*	7				x	x
Pheasant Coucal *Centropus phasianinus*	3				x	x
Brush Cuckoo *Cacomantis variolosus*	1				x	x
Tawny Frogmouth *Podargus strigoides*	1				x	x
Barking Owl *Ninox connivens*	5				x	
Azure Kingfisher *Ceyx azureus*	1			x	x	
Blue-winged Kookaburra *Dacelo leachii*	7				x	x
Forest Kingfisher *Todiramphus macleayii*	7				x	x
Sacred Kingfisher *Todiramphus sanctus*	5				x	x
Rainbow Bee-eater *Merops ornatus*	6				x	x
Black-tailed Treecreeper *Climacteris melanura*	5					x
Great Bowerbird *Ptilonorhynchus nuchalis*	7				x	x
Red-backed Fairy-wren *Malurus melanocephalus*	3					x
Striated Pardalote *Pardalotus striatus*	2					x
Weebill *Smicrornis brevirostris*	4					x
Silver-crowned Friarbird *Philemon argenticeps*	2				x	x
Little Friarbird *Philemon citreogularis*	4				x	x
Blue-faced Honeyeater *Entomyzon cyanotis*	3				x	x
White-gaped Honeyeater *Lichenostomus unicolor*	7				x	x
White-throated Honeyeater *Melithreptus albogularis*	7					x

Table 1. Continued.

Species	F	C	OW	WE	RF	SW
Rufous-banded Honeyeater *Conopophila albogularis*	2				x	
Brown Honeyeater *Lichmera indistincta*	7				x	x
Dusky Honeyeater *Myzomela obscura*	1				x	x
Grey-crowned Babbler *Pomatostomus temporalis*	1				x	x
White-bellied Cuckoo-shrike *Coracina papuensis*	7				x	x
Varied Triller *Lalage leucomela*	3				x	
Grey Shrike-Thrush *Colluricincla harmonica*	4					x
Rufous Whistler *Pachycephala rufiventris*	2					x
Australasian Figbird *Sphecotheres vielloti*	4				x	
Yellow Oriole *Oriolus flavocinctus*	7				x	
Olive-backed Oriole *Oriolus sagittatus*	2				x	
White-breasted Woodswallow *Artamus leucorhynchus*	4			x	x	
Grey Butcherbird *Cracticus torquatus argenteus*	4				x	x
Spangled Drongo *Dicrurus bracteatus*	7				x	x
Willie Wagtail *Rhipidura leucophrys*	5					x
Northern Fantail *Rhipidura rufiventris*	6				x	x
Torresian Crow *Corvus orru*	7				x	x
Shining Flycatcher *Myiagra alecto*	7				x	
Restless Flycatcher *Myiagra inquieta nana*	4				x	
Leaden Flycatcher *Myiagra rubecula*	4				x	x
Australian Magpie-lark *Grallina cyanoleuca*	2				x	x
Lemon-bellied Flycatcher *Microeca flavigaster*	7				x	
Mistletoebird *Dicaeum hirundinaceum*	6				x	x
Tree Martin *Petrochelidon nigricans*	1		x	x		
Crimson Finch *Neochmia phaeton*	1				x	
Double-barred Finch *Taeniopygia bichenovii*	1				x	x
Total species			**11**	**24**	**59**	**45**

Discussion

Surveys of the avifauna at Manton Dam revealed an abundant bird fauna, with 84 species recorded. However, compared with other wetland sites in northern Australia, Manton Dam has a low diversity of waterbirds (22 species). For example, at Fiddlers Lane (Knuckeys Lagoon), a comparatively small wetland near Darwin, 30 waterbird and 10 wader species have been recorded (S. Reynolds, unpubl.). At Kidneybean Claypan on Roebuck Plains near Broome, 35 waterbird and more than 20 wader species have been observed (Rogers *et al.* 2001), and at Fogg Dam 39 waterbird species have been recorded (Crawford 1979). The freshwater wetlands of Kakadu National Park support more than 40 species of waterbird and 20 species of shorebird (Bamford 1990; Press *et al.* 1995). At Lake Kununurra (an impoundment of the Ord River, Western Australia), 55 waterbird species have been recorded, including 18 breeding at the site. Lake Argyle in the Kimberley, an important dry season refuge, supports 48 species of waterbird and 26 species of shorebird (ANCA 1996).

Natural water bodies in northern Australia, including lagoons and floodplains, expand and contract dramatically over the course of the year with many areas drying out completely (Finlayson *et al.* 1990; Kingston 1991; Cowie *et al.* 2000). The shallow and exposed muddy fringes of wetlands provide an important food resource for waterbirds that have adopted a range of foraging strategies specifically for such habitats (Cowie *et al.* 2000; Morton & Brennan 1991). In contrast to many wetlands where waterbirds congregate during the dry season (Crawford 1979), and the floodplains of Kakadu, where ducks, herons, egrets and ibis may occur in the thousands (Morton *et al.* 1990, 1993), Manton Dam is a poor dry season refuge. Therefore, it is not surprising that of the nomadic ducks (e.g. Grey Teal *Anas gracilis*) and herons (e.g. White-faced Heron *Egretta novaehollandiae*) from southern Australia that seek out shallow freshwater swamps in monsoonal northern Australia (Morton & Brennan 1991), only Pink-eared Duck was recorded (Table 1). The shallow water habitat of Manton Dam was used by egrets, Radjah Shelduck and Magpie Geese, as well as Green Pygmy-geese which feed on aquatic plants (Blakers *et al.* 1984). The relatively deep water (average 4 m) of Manton Dam provided good foraging habitat for the Australasian Darter and cormorants.

In the Kimberley of Western Australia and the Top End of the Northern Territory rainforest occurs as patches (Russell-Smith 1991; Price 2006). Johnstone and Burbidge (1991) identified a range of bird species that are largely confined to rainforest in the Kimberley. Of these species, Pied Imperial-Pigeon, Emerald Dove, Varied Triller, Yellow Oriole, Australasian Figbird and Spangled Drongo were recorded from the rainforest patch at Manton Dam. A range of species (Brown Goshawk, Bar-shouldered Dove, Peaceful Dove, Blue-winged Kookaburra, Northern Fantail, Leaden Flycatcher, and Double-barred Finch) tend to be more abundant in riparian forests than in adjacent habitats (Woinarski *et al.* 2000); in this study these species

were all recorded from both rainforest and woodland habitats. Barking Owl and the nests of several species (Lemon-bellied Flycatcher, Shining Flycatcher, White-bellied Sea-Eagle and Forest Kingfisher) were only found in rainforest habitat.

The greater density of trees, structural diversity, and enhanced availability of cover, nesting and food resources in riparian and rainforest habitats account for the greater diversity of bird species in these habitats compared with savanna woodland (Johnstone & Burbidge 1991; Woinarski *et al.* 2000). The difference in species richness between the two habitats (RF: 59, SW: 45) in this study is likely to be at least partly due to these factors.

Fruiting trees were mainly found in rainforest habitat in this study; they are commonly associated with monsoon forests where they may produce thousands of fruit per tree (Bach 1998) and are an important resource for frugivorous birds. Australasian Figbird and Varied Triller are particularly attracted to figs (Storr 1980) and were observed feeding on the small fruit of *Ficus virens* in September, along with White-bellied Cuckoo-shrike and Mistletoebird. Great Bowerbird is known to consume the fruit of *Canarium australianum* and, near the picnic area, this bird may have been a factor in the dispersal of this pioneer species (Bach 1998). The fruit of *Carallia brachiata, Breynia cernua, Alphitonia excelsa, Pouteria sericea* and *Opilia amentacea* are also likely to have been dispersed by birds (Wightman & Andrews 1989). Frugivorous birds, such as Yellow Oriole, Australasian Figbird and Pied Imperial-Pigeon, are important seed dispersers and occurred only in rainforest habitat. Frugivores can digest the outer pericarp of fruit but not the seed, which is left intact. The seeds can then be deposited when these birds move between monsoon forest patches, distances of up to 10 km (Price 2006).

Numbers of honeyeaters, the most diverse passerine family in this study (Table 1), fluctuated in response to the flowering of paperbarks around the dam. For example, Brown Honeyeater was highly abundant during most surveys but was represented by a single record in September 2011. It is likely that other honeyeater species occur at Manton Dam when different plants are flowering.

Among raptors, Whistling Kites were frequently present near water in low numbers and a Black Kite was observed at fires in woodland habitat in late April. White-bellied Sea-Eagles were observed on a nest at the east side of the dam in 2005 and 2010, but no nests were present in 2011. This species may occur far inland, as for example at Lake Argyle (Storr 1980), and will colonise and breed on most large reservoirs (Blakers *et al.* 1984).

Species which occur at low densities, are seasonal or nomadic visitors, or which are relatively inconspicuous to an observer, are often infrequently recorded (Reynolds 2010). In this study, the secretive Black Bittern was observed only once, in fringing paperbark forest. Black Bitterns occupy dense waterside vegetation

(Storr 1980) and, although generally nocturnal or crepuscular, can sometimes be flushed during the day (Sedgwick 1946).

Species not recorded that are likely to occur at Manton Dam include seasonal or nomadic visitors (Dollarbird *Eurystomus orientalis*, Eastern Koel *Eudynamys orientalis*, Bar-breasted Honeyeater *Ramsayornis fasciatus*), uncommon species (Northern Rosella *Platycercus venustus*, Grey Goshawk *Accipiter novaehollandiae*, Buff-sided Robin *Poecilodryas cerviniventris*), rainforest inhabitants (Green-backed Gerygone *Gerygone chloronata*, Rainbow Pitta *Pitta iris*), nocturnal species and other waterbirds and raptors. Surveys in the wet season would likely uncover additional seasonal visitors, and surveys of the wetland fringes as they become exposed in the late dry season (September-November) may uncover migratory shorebirds on their southern migration (Shurcliff 1993). Interestingly, it was not until 2011 that any Crimson Finch were observed in the stands of *Pandanus* (RF habitat), a vegetation type where this species is usually abundant. I am unable to account for the unusually low density of this species at Manton Dam despite apparently suitable habitat.

In summary, the extensive distribution of riparian forest around the dam provides comparatively large areas of habitat suitable for a range of bushbirds. By contrast, the observed diversity of waterbirds was poor in comparison to other water bodies in Northern Australia. Changes in vegetation and the presence of permanent water are likely to have influenced the diversity and species composition of the birdlife, and further surveys may uncover additional species utilising the area. Habitat quality for wading birds could be improved by landscaping parts of the dam to provide gently shelving areas with exposed muddy fringes which are important foraging sites for waterbirds, thus increasing the area's similarity to other wetlands that act as important dry season refuges. If Manton Dam again becomes a water supply for Darwin (as has been mooted), it may be closed to motorised craft, which may encourage more waterbirds to use the wetland area.

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First record of Spotted Whistling Duck *Dendrocygna guttata* for the Northern Territory

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Abstract

The Spotted Whistling Duck *Dendrocygna guttata* occurs in the Philippines, Indonesia and Papua New Guinea and was first recorded in Australia in 1995; it is now seen regularly in northern Queensland. The first record of the species in the Northern Territory, which is also the first Australian record outside Queensland, is presented here. A single bird was observed on six occasions from 27 December 2011 to 12 February 2012 at the Leanyer Sewage Ponds, Darwin. The initial observation was made immediately following a tropical cyclone, which formed in the Arafura Sea and tracked south to make landfall east of Darwin, suggesting that the bird may have originated from eastern Indonesia rather than Queensland.

The Spotted Whistling Duck *Dendrocygna guttata* occurs in the southern Philippines, Sulawesi to the Moluccas and the Tanimbar Islands, Indonesia, and Papua New Guinea (del Hoyo *et al.* 1992; Coates *et al.* 1997). It was first recorded in Australia in 1995 when several birds were located at Weipa on Cape York Peninsular, Queensland (Niland 1996). It is now regularly observed on Cape York Peninsular, in particular in the Weipa and Iron Range areas, but with records from as far south as Wonga Beach, between Mossman and Daintree Village, north of Cairns (Wildiaries 2011). The species has also been recorded in the Torres Strait, essentially connecting the Cape York Peninsular records with its wider range to the north (BARC Submisson Nos. 331 and 392). Beruldson (2002) suggested that the species may be breeding in Australia, based on observations and behaviour of an adult pair with six juvenile birds. However, this conclusion may have overlooked the nomadic nature of the species and a local breeding event has not yet been confirmed (BARC Submission No. 319; Beruldson 2002). The current report is the first record for the species from the Northern Territory and the first Australian record outside Queensland. This record has been accepted by the Birds Australia Rarities Committee (BARC Submission No. 750, T. Palliser, pers. comm., 16 September 2012).

A single Spotted Whistling Duck was found on 27 December 2011 at Leanyer Sewage Ponds, Darwin, Northern Territory (12°21'45"S, 130°54'33"E), and was present until at least 12 February 2012 (Figures 1–2). It was observed by the author on

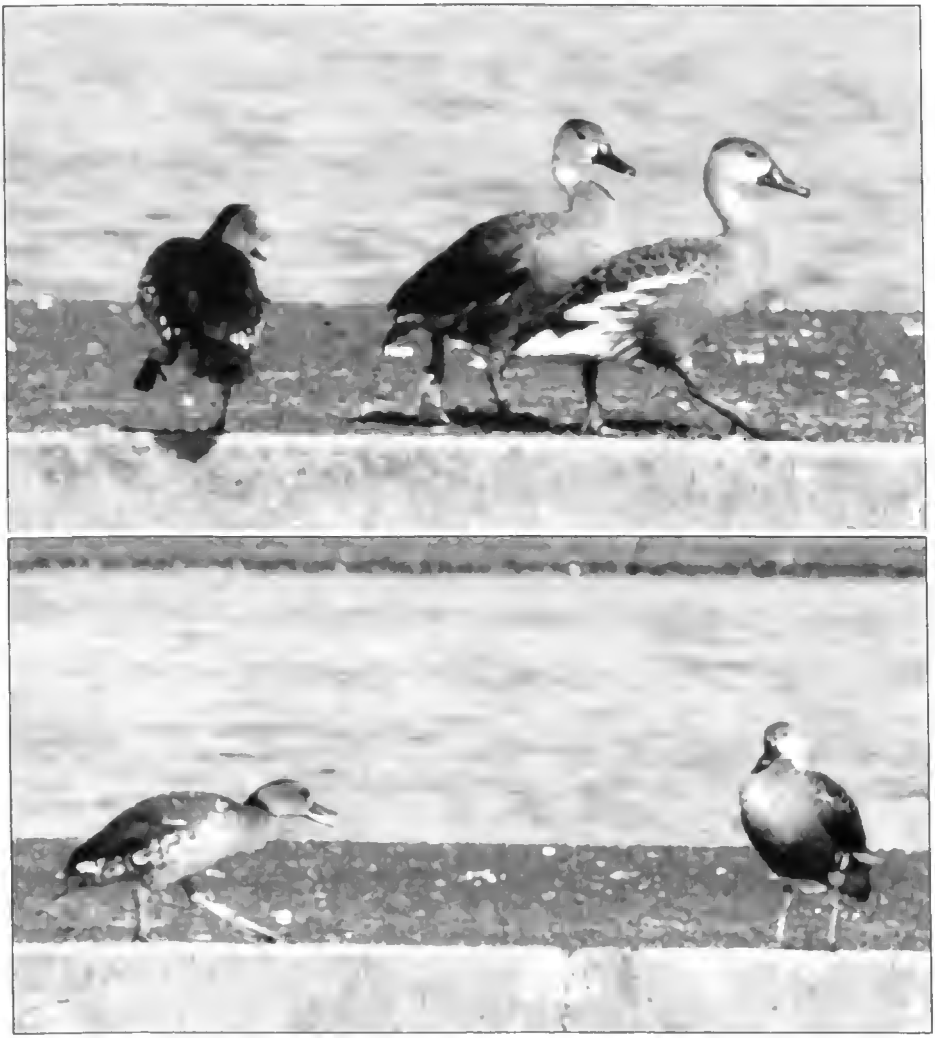
six occasions between those dates (additional dates: 7, 9, 11, and 26 January 2012). Repeated visits on other dates during that time period did not produce any further records, nor did visits after 12 February 2012. The bird was generally resting close to the water's edge, but on occasion was observed preening, drinking and, when disturbed, making short flights during which it landed on the water, where it swam for brief periods before returning to dry land. Although a variety of other ducks were present, predominantly Wandering Whistling Duck *D. arcuata* and Radjah Shelduck *Tadorna radjah*, the individual often remained at some distance from these birds. During earlier sightings the bird was harassed regularly by other ducks, in particular Wandering Whistling Ducks, and appeared very nervous. During later observations, by contrast, the individual was itself more aggressive towards other ducks (Figures 3–4). The bird was flighty throughout the sighting period, and did not allow close approach; observations were generally made from a range of 100–150 m.

The bird was identified as a Spotted Whistling Duck by the prominent white spots on the flanks and breast (irregular-sized spots on the flanks; small spots scattered over the breast); grey face, eyebrow and sides of the neck; blackish/dark brown crown, nape and hindneck (black/dark brown extended onto the sides of the neck to form a partial collar); blackish/dark brown eye patch and lores; dark brown back; rich buff-rufous on the sides of the upper breast/lower neck; and dull pink legs with blackish feet. A narrow white bar on the upper tail-coverts was noticeable in flight. The bill was dark without any obvious red; there was an area of white at the base of the bill.

Wandering Whistling Ducks (Figures 2–4) were present during all observations, and Plumed Whistling Ducks *D. eytoni* were also at the site during some observations, allowing close comparison of the individual with these two species. Both of these species lack white spots, have pale brown to buff faces, have flank-plumes (short in Wandering Whistling Duck; long and upswept in Plumed Whistling Duck), and have different overall colouration (Wandering Whistling Duck has rich chestnut flanks with dark scaling on the breast; Plumed Whistling Duck is paler with broad dark bands on cinnamon outer breast to mid-flanks) (Marchant & Higgins 1990). The Lesser Whistling Duck *D. javanica*, which has not been recorded from Australia but occurs in Indonesia including the Lesser Sundas, lacks white spots, is smaller, and has an overall colouration which is similar to the Wandering Whistling Duck (del Hoyo *et al.* 1992; Coates *et al.* 1997).

The white spots on the flanks suggest that the bird was an adult; juveniles have white streaks instead of spots on the flanks (del Hoyo *et al.* 1992; Coates *et al.* 1997). However, the spotting was generally irregular and did not resemble that illustrated in guides, nor did the bill colouration, which is usually illustrated wholly or partially red (e.g. del Hoyo *et al.* 1992; Coates *et al.* 1997; Pizzey & Knight 2007). The spots are

Figures 1–2. Spotted Whistling Duck *Dendrocygna guttata*, Leanyer Sewage Ponds, Darwin, Northern Territory: **1.** 9 January 2012 (Micha V. Jackson); **2.** 11 January 2012 with Wandering Whistling Ducks *D. arcuata*. (Peter M. Kyne)



Figures 3–4. Spotted Whistling Duck *Dendrocygna guttata*, Leanyer Sewage Ponds, Darwin, Northern Territory, 9 January 2012, displaying aggressive behaviour towards Wandering Whistling Ducks *D. arcuata*. (Micha V. Jackson)

typically messy in this species and the bill usually appears dark at a distance, with closer observation required to detect colouration (J. Davies, pers. comm., 1 July 2012).

The initial sighting immediately followed Tropical Cyclone Grant, which formed in the Arafura Sea and generally tracked southwards, making landfall on the Cobourg Peninsula on 25 December 2011 and then in the Alligator Rivers region east of Darwin on 26 December 2011. I therefore hypothesise that the bird originated from eastern Indonesia, which lies to the north of Darwin, rather than from Queensland. Parts of the species' range, such as the Tanimbar Islands, are considerably closer to Darwin (~450 km due north) than is Cape York (~1,200 km due east), and the preceding weather patterns support this proposed origin of the bird.

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Northern Territory Naturalist (2013) 24: 55–60 Short Note

Red-rumped Swallow *Cecropis daurica* in the Northern Territory

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Abstract

The Red-rumped Swallow *Cecropis daurica* is an irregular visitor to Australia during its non-breeding season. We present an account of records of this species in the Northern Territory (NT), Australia. Photographs are provided for two previously undocumented records, resulting in a total of seven reported occurrences in the NT. Red-rumped Swallow has been recorded between October and April, often in association with other hirundinid species. Subspecific identification of NT records is not definitive and observers are encouraged to carefully document additional occurrences.

The Red-rumped Swallow *Cecropis daurica* is a widespread Eurasian migratory swallow, with irregular occurrences in northern Australia, where the species was first recorded in 1983 (Higgins *et al.* 2006). Turner (2004) recognised ten subspecies while the current IOC Checklist, Version 3.1 (Gill & Donsker 2012), recognises eight (others having been elevated to full species). BirdLife International (2012) has lumped the species with Striated Swallow *Cecropis striolata*, and retains the generic placement in *Hirundo*. Turner (2004) suggests that DNA studies support separate genera rather than *Hirundo sensu lato*. Here we follow the IOC (Gill & Donsker 2012) for clarity, however, we note that taxonomic resolution may show Red-rumped Swallow and Striated Swallow to be the same species.

Three Red-rumped Swallow subspecies have wintering ranges that include South-East Asia, and are those most likely to occur in Australia. *Cecropis daurica japonica* is said to winter in South-East Asia (Turner & Rose 1989; Robson 2008), and northern Australia (Turner 2004; Gill & Donsker 2012). The ranges of the nominate *C. d. daurica* and *C. d. nipalensis* remain unclear. Most authors state that the winter range of *C. d. daurica* includes parts of South-East Asia, while *C. d. nipalensis* winters in India and possibly Myanmar (Turner & Rose 1989; Turner 2004; Gill & Donsker 2012); however Robson (2008) lists *C. d. nipalensis* as occurring in South-East Asia,

but indicates uncertainty as to whether it is widespread in the region or restricted to Myanmar, and does not list *C. d. daurica* for South-East Asia.

The majority of Australian records and reports of Red-rumped Swallow are from north-eastern Queensland (particularly the Mossman-Daintree River area) and around Broome and Kununurra in north-western Western Australia (Higgins *et al.* 2006). Here, we present an account of the species in the Northern Territory (NT).

The earliest report that appears in the literature of the species in the NT is from East Point, Darwin in October 1999 (Higgins *et al.* 2006). From December 1999 to January 2000 up to 18 birds were reported on Groote Eylandt (Noske & Brennan 2002; Higgins *et al.* 2006) (Table 1). This is the only known occurrence of a group of Red-rumped Swallows reported in the NT. No photographs or specimens are currently available from either of these reports.

All subsequent reports of the species occurred at the Leanyer Sewage Ponds in Darwin (12°21'39"S, 130°54'39"E): a 2003 record is described in BARC Submission No. 390; a 2005 report is listed as an unconfirmed report in Higgins *et al.* (2006); and a 2006 record is described in BARC Submission No. 483 (Table 1). Two additional, previously undocumented records are reported here.

Table 1. Summary of all reported occurrences of Red-rumped Swallow *Cecropis daurica* in the Northern Territory, Australia.

Date	Location	Reference
October 1999	East Point, Darwin	Higgins *et al.* (2006)
05 December 1999 – 29 January 2000	Various sites, Groote Eylandt	Noske & Brennan (2002)
20 February 2003	Leanyer Sewage Ponds, Darwin	BARC Submission No. 390
11 March 2005	Leanyer Sewage Ponds, Darwin	Higgins *et al.* (2006)
16–17 March 2006	Leanyer Sewage Ponds, Darwin	BARC Submission No. 483
23 February – 01 March 2008	Leanyer Sewage Ponds, Darwin	A. Carlson, pers. comm. (including photos); S. Keates, pers. comm.; current report
18 April 2010	Leanyer Sewage Ponds, Darwin	Current report

The first previously undocumented record is of two separate sightings from 23 February and 1 March 2008 from the Leanyer Sewage Ponds (A. Carlson, pers. comm.). Figure 1 shows an individual photographed on 23 February 2008 and Figure 2 shows an individual photographed on 1 March 2008. Given the timing of these two sightings, it is probable that these records represent the same individual. A Red-rumped Swallow was also reported from Leanyer Sewage Ponds on 24 February 2008 (S. Keates, pers. comm.) and this was presumably the same individual, although no photographs are available.

The second previously undocumented record, and the most recently reported NT sighting, was of one individual observed and photographed by the authors in 2010. During the late afternoon of 18 April 2010, the individual (Figures 3–5) was observed and photographed flying over the north-east portion of the Leanyer Sewage Ponds. It was observed for about 30 minutes hawking insects above the ponds in the company of a large number of Tree Martins *Petrochelidon nigricans*. At the end of the observation period the bird gained altitude and flew in a westerly direction.

Several features easily separate the 2008 and 2010 individuals from Barn Swallow *Hirundo rustica* and Welcome Swallow *H. neoxena*, which can occur seasonally in the Top End of the NT. The individual in Figure 1 shows prominent orange-rufous on the side of the head, which extends towards the back of the neck; in Figure 2 the individual shows extensive orange-rufous on the side of the head. The individual

Figures 1–2. Red-rumped Swallow *Cecropis daurica*, Leanyer Sewage Ponds, Darwin, Northern Territory: **1.** 23 February 2008; **2.** 1 March 2008. (Ashley Carlson)

in Figures 3–5 similarly displays prominent orange-rufous on the side of the head, which appears in Figure 3 to extend towards the back of the head, although it is unclear whether the collar is complete. The birds shown in Figures 1–5 are extensively streaked and display a prominent orange-rufous rump (Figures 1; 3). The individual in Figures 1–2 shows rufous tones to the underparts. The individual in Figures 3–5 displays buffy-rufous underwing-coverts and black undertail coverts (also seen in the individual in Figure 2). Both Barn Swallow and Welcome Swallow lack the orange-rufous rump and nuchal collar, and streaking (Higgins *et al.* 2006).

More difficult is differentiating Red-rumped Swallow from Striated Swallow, which, as noted above, is considered a subspecies by BirdLife International (2012) and also occurs in South-East Asia (Higgins *et al.* 2006). The streaking on the individuals in Figures 1–5 seems consistent with Red-rumped Swallow; this streaking is not as dark or bold as in Striated Swallow (see photographs of Striated Swallow in Carter 2000). The rufous tones of the underparts are also consistent with Red-rumped Swallow

Figures 3–5. Red-rumped Swallow *Cecropis daurica*, Leanyer Sewage Ponds, Darwin, Northern Territory, 18 April 2010: **3.** Upperwing view; **4.** Underpart view; **5.** underwing view. (Micha V. Jackson)

(Carter 2000; Turner 2004). Both Carter (2000) and Turner (2004) note that Red-rumped Swallow can have an incomplete rufous collar, while the collar is indistinct or absent in Striated Swallow. It is unclear from Figures 1–5 how much of a nuchal collar exists on the photographed individuals. The extensive orange-rufous colour on the side of the head, which is clearly visible on the individuals in Figures 1–5, is vestigial in Striated Swallow according to Carter (2000). The strong buffy-rufous wash on the underwing-coverts and underparts of the individual in Figures 3–5 also suggest Red-rumped Swallow (Turner & Rose 1989; Carter 2000; Turner 2004), though Turner (2004) states that the underwing-coverts of Striated Swallow also have a buffy wash. The streaking on the underparts of Striated Swallow is broader and darker than on Red-rumped Swallow, though the difference between the Red-rumped Swallow subspecies *C. d. japonica* and all races of Striated Swallow (particularly *C. s. striolata*) can be marginal and should not be used as the only separating feature according to Carter (2000). This applies particularly in the case of the individual in Figure 2, which is heavily streaked.

Most documented occurrences from the Leanyer Sewage Ponds were in association with other hirundinid species; the 2003 (BARC Submission No. 390), 2008, and 2010 records were in association with Tree Martins, and the 2006 record (BARC Submission No. 483) with Barn Swallows. Tree Martins migrate from more southerly areas of Australia, generally visiting the area from late March – April to September – November (Higgins *et al.* 2006) while Barn Swallows visit the region from Eurasia generally between September and April (Higgins *et al.* 2006). All reported occurrences from Leanyer have been in the months of February, March and April. The Groote Eylandt birds reported by Noske and Brennan (2002) were observed from early December to late January, while the first Darwin report from 1999 was in October (Higgins *et al.* 2006) (Table 1). This timing is generally consistent with the southern occurrence of non-breeding birds that have migrated from Eurasia.

We note that three Red-rumped Swallow subspecies, namely *C. d. daurica, C. d. nipalensis*, and *C. d. japonica*, possibly occur in Australia based on their wintering ranges as reported by various sources (Turner & Rose 1989; Turner 2004; Higgins *et al.* 2006; Robson 2008, Gill & Donsker 2012). However, separation of these subspecies is unclear, making it difficult to identify to subspecific level the individuals observed in the NT. Higgins *et al.* (2006) state that the limited available data suggest *C. d. japonica* for Australian occurrences, but add that this needs further investigation. The two Australian specimens of Red-rumped Swallow that have so far been examined have been assessed as *C. d. japonica* on the basis of their size and comparison with museum material (Carter 2000). We suggest that the 2008 and 2010 individuals documented in this paper were potentially *C. d. japonica* based on the clear, heavy streaking; *C. d. japonica* is the most heavily streaked of the group (Carter 2000; Turner 2004) and, according to Turner (2004), is intermediate between *C. d. daurica*

and Striated Swallow (see Turner & Rose (1989), Carter (2000) and Turner (2004) for subspecies identification).

Carter (2000) notes an increasing number of records of both Red-rumped Swallow and Striated Swallow in New Guinea and a claimed occurrence of Striated Swallow in Queensland. Observers should carefully scan any group of martins and swallows during the northern Australian wet season for additional occurrences, keeping in mind that Red-rumped Swallows in worn non-breeding plumage may easily be overlooked. Given the difficulties in separating the various Red-rumped Swallow subspecies and similarities with Striated Swallow (which may also be a subspecies of the former), suspected occurrences should be well documented and photographed when possible to contribute to further knowledge on subspecific identification.

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Northern Territory Naturalist (2013) 24: 61–64 Short Note

An insectivorous Australian Pratincole *Stiltia isabella* diversifies its diet

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Abstract

Pratincoles and coursers (family Glareolidae), including the primarily ground-feeding Australian Pratincole *Stiltia isabella*, are principally insectivorous. This paper presents a brief note on the first documented occurrence of Australian Pratincole (and indeed a rare record of any glareolid bird) feeding on vertebrate prey, in this case a small frog.

The family Glareolidae is made up of two distinct sub-families, the coursers (Cursoriinae) and the pratincoles (Glareolinae), both of which are principally insectivorous (del Hoyo *et al.* 1996; Higgins & Davies 1996). Coursers are mostly ground feeders while pratincoles are mostly aerial feeders; the exception is the Australian Pratincole *Stiltia isabella* (the sole member of its genus), which forms a link between the two groups and is the only pratincole to feed primarily on the ground (Maclean 1976; del Hoyo *et al.* 1996). Stomach contents and feeding records indicate that a diversity of insects constitute the species' diet, with additional prey items including centipedes (Myriapoda) and spiders (Arachnida) (Maclean 1976; Barker & Vestjens 1989; Higgins & Davies 1996). While del Hoyo *et al.* (1996) state that glareorids will sometimes take small lizards, they do not indicate the group or species for which this has been recorded. Here we present a brief note on the first documented occurrence of Australian Pratincole (and indeed a rare record of any glareolid bird) feeding on vertebrate prey.

On the morning of 6 October 2011, an Australian Pratincole was observed and photographed consuming a frog on a private watermelon farm in Lambells Lagoon, Northern Territory, Australia (12°33'22"S, 131°14'51"E) (Figures 1–4). When the pratincole was first observed, the frog was already in its bill (the capture event itself was not witnessed). The frog appeared limp and movement was not noted. It is therefore uncertain if the pratincole killed the prey, or if it scavenged an already dead frog. The habitat was an agricultural field of largely open dry soil, with a subsurface irrigation system that is known to provide habitat for a variety of frog species (D. Webb, pers. comm.). There was a large number of actively feeding inland

shorebirds present on the property, including an estimated 1000+ Little Curlew *Numenius minutus* and smaller numbers of Oriental Plover *Charadrius veredus* and Australian Pratincole.

Based on reported measurements of bill length in Australian Pratincole (~12–16 mm; Higgins & Davies 1996), the size of the frog was estimated to be <20 mm snout to vent length (SVL). While a definitive identification of the frog (Figures 5–6) is not possible given the distance of the observation, the most likely species can be inferred based on its general form and structure and the occurrence of local fauna (based on Tyler & Davies 1986; Tyler & Knight 2009; S. Richards, pers. comm.). The general form, leg length, toe length, unwebbed toes, and the lack of brown speckles and flecks on the belly rule out the Cane Toad *Rhinella marina*. Frogs of the family Hylidae (tree frogs including the genera *Litoria* and *Cyclorana*) can be discounted due to the lack of webbing and the lack of adhesive discs on the toes. General form, unwebbed toes and white belly match that of the Marbled Frog *Limnodynastes convexiusculus* and the Ornate Burrowing Frog *Platyplectrum ornatum* (family Limnodynastidae), although

Figures 1–4. Australian Pratincole *Stiltia isabella*, Lambells Lagoon, Northern Territory, 6 October 2011, feeding on a frog, most likely of the genus *Crinia*. (Micha V. Jackson)

both of these are larger frog species (*L. convexiusculus* up to 61 mm SVL, *P. ornatum* up to 45 mm SVL; Tyler & Knight 2009). The apparent white belly, long legs and lack of digital discs means that it is not the Northern Territory Frog *Austrochaperina adelphe*, the only frog of the family Microhylidae found in the region. The unwebbed toes and small size are consistent with frogs of the family Myobatrachidae; the long legs and body shape do not match *Uperoleia* species (native toadlets), but observable features, including small size, are consistent with froglets of the genus *Crinia* (Bilingual Froglet *C. bilingua* and Remote Froglet *C. remota*), which are known locally (S. Richards, pers. comm.) and represent the most likely candidates.

Species are often categorised, in a simplified form, as either generalist (opportunist) or specialist feeders (Glasser 1982). However, there can be variation in diet between individuals within a population (Durell 2000) and plasticity of diets can result from opportunities to exploit different prey which are energetically beneficial. While the Australian Pratincole can be considered a specialist insectivore, pratincoles on the

Figures 5–6. Enlarged photos of a frog, most likely of the genus *Crinia*, consumed by an Australian Pratincole *Stiltia isabella*, Lambells Lagoon, Northern Territory, 06 October 2011, showing two diagnostic features: **5.** Lack of webbing and lack of digital discs on the toes; **6.** White belly. (Micha V. Jackson)

whole have been described as opportunists, taking advantage of temporarily available insect prey, such as winged termites (del Hoyo *et al.* 1996), and therefore adjusting their prey choice as opportunities arise. This may extend to any prey, invertebrate or vertebrate, that is available and accessible. While gape limitation may be a restriction on the size range of prey that can be taken (Zwarts & Blomert 1992), the Australian Pratincole is adept at taking relatively large prey, including beetles up to about 25 mm and dragonflies up to 80 mm in length (Maclean 1976).

The observed Australian Pratincole had little trouble manipulating and swallowing the frog, indicating that gape width and depth did not limit the selection of this prey (the soft skin of a frog might also make its size less restrictive compared with the exoskeleton of insects like beetles). While del Hoyo *et al.* (1996) note that glareorids will sometimes take small lizards, our observation represents rare documentation of a species whose family has been described as 'entirely insectivorous' (Higgins & Davies 1996) feeding on vertebrate prey. Further observations may indicate whether or not vertebrates (either scavenged or hunted) constitute a more frequent component of the Australian Pratincole's diet.

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Northern Territory Naturalist (2013) 24: 65–67 Short Note

First confirmed sighting of the Killer Whale *Orcinus orca* in Northern Territory coastal waters

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Abstract

The first confirmed sighting of the Killer Whale *Orcinus orca* in Northern Territory coastal waters is reported here. It highlights the importance of members of the public taking the time to submit photos and information to the Marine WildWatch Hotline.

A school of 3-5 Killer Whales *Orcinus orca* in coastal waters off north-eastern Arnhem Land was recorded by three recreational fishers on the 31 March 2012. The fishermen took a number of photos of these impressive marine mammals as the animals hunted in the shallow waters off the Bromby Islands (Figures 1–2). From these photos we were able to confirm the first official sighting of the species in Northern Territory waters. Previously, there have only been unconfirmed sightings of Killer Whales in the NT, including those by aboriginal elders from the Yirrkala area, a possible sighting of a pod of 5-6 animals close to the bauxite plant at Gove in the early 1990s (R. Chatto unpubl.), and an unconfirmed report off Yirrkala in 1999 (Chatto & Warneke 2000).

Killer Whales are the world's largest dolphin species, the top marine predator globally and perhaps the most widespread vertebrate on earth, occurring in all the world's oceans (Pitman 2011). Although currently considered to be a single species worldwide, recent research in Antarctic waters has revealed that there are at least four distinct forms of Killer Whales (referred to as types A, B, C and D) based on saddle and eye patch shapes and colouration (Pitman 2011).

Overall, there is little information on the species in the tropics and sightings are rare. In Hawaiian waters, there have been two sightings of Killer Whales in 12 years and these sightings indicated that the saddle patches of tropical Killer Whales tend to be much darker and narrower than in more temperate populations (R.W. Baird pers. comm.). Interestingly, one of the Killer Whales photographed in Northern Territory waters had a relatively dark saddle patch similar to the Killer Whales recorded in Hawaiian waters (Baird *et al.* 2006).

Figures 1–2. Killer Whale off the Bromby Islands, north-eastern Arnhem Land, Northern Territory, 31 March 2012. (David Francis)

A number of research organisations that monitor Killer Whales – the National Oceanic and Atmospheric Administration's Southwest Fisheries Science Centre and the Cascadia Research Collective based in Hawaii – have been notified of this rare sighting, which will add to a better global understanding of the species.

Under Commonwealth Legislation, the Killer Whale is listed as a Cetacean and Migratory under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). Internationally, the species is listed under Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS 1985) and under Appendix I on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2012). Under the IUCN (2012), the species is classified as Lower Risk.

The sighting of Killer Whales in Northern Territory waters is an important record and highlights a rare occurrence. Moreover, it emphasises the importance of the public reporting marine mammal sightings and taking photos when possible.

Please report all marine mammal sightings to: Marine Wildwatch Hotline on 1800 453 941.

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A key to the potamidid snails (longbums, mudcreepers and treecreepers) of northern Australia

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Abstract

Longbums and the smaller mudcreepers and treecreepers (Mollusca: Gastropoda: Cerithioidea: Potamididae) are amphibious surface-dwellers of tidal wetlands intimately associated with mangrove forests, depending on the trees for shelter from heat and desiccation, as a substrate, for food, and for protection from predators. A dichotomous key is presented to identify the eight species of Potamididae that occur in tropical northern Australia, several of which have similar looking shells. These species represent 27.6% of the global biodiversity for the family. This contribution describes the most useful features for distinguishing between species, and provides comments on habitat, ecological niche and geographical range of each species, with notes on exploitation by Aborigines. One species of true creeper, *Cerithium coralium* (Cerithioidea: Cerithiidae), is also included because it lives with, and may be easily confused with, juvenile longbums and/or the smaller potamidid species.

Introduction

Since I came to the Northern Territory in 1992, I have fielded more questions about longbums than any other group of molluscs. This might seem strange because they have little commercial significance (though once I saw frozen *Telescopium telescopium* for sale at Casuarina Square Shopping Centre) and their shells lack intrinsic beauty. However, they have huge ecological importance in mangrove forests and in the diets of coastal Aboriginal peoples. I quickly found the taxonomy, anatomy, behaviour and habitats of longbums and other members of the family Potamididae were a source of great interest to a lot of people. I also worked out that there were eight species in tropical northern Australia, constituting 27.6% of the global biodiversity for this family.

The shells of several species of Potamididae look very similar, especially when daubed with mud and/or algal turf, or encrusted with oysters and/or barnacles in the field, so I had to develop a reliable method of distinguishing between them correctly. This method, now refined from experience, is here codified into a dichotomous key together with the latest scientific names for all the species that occur in tropical northern Australia. Keys are not often produced to identify molluscs because, being based on subjective characters that change as the shells grow (ontogenetic

variation), they are extraordinarily hard to generate. Yet keys can be invaluable when they are finally tested and 'foolproof'. I discovered the power of keys for molluscs when I generated one for the intertidal trochid molluscs of the genera *Zediloma* and *Melagraphia* [now all in the genus *Diloma*] in New Zealand (Willan 1980), another group of molluscs that is difficult to distinguish by their shells. Poutiers (1998 pp. 448–449) has published a key to the six potamidid species of interest to fisheries in the western central Pacific Ocean, four of which occur in northern Australia.

The colloquial name longbum is unique to the Northern Territory. Strictly it applies to the four larger members of the family Potamididae (*Telescopium telescopium, Terebralia palustris, Terebralia semistriata* and *Terebralia sulcata*). The name longbum alludes to the long, sinuous trail of faeces left behind an animal after it has been feeding on detritus on the surface of mangrove mud. I have never found out where, or when, the name longbum was first coined. The four other, smaller, species of the family that also occur in northern Australia are known less colourfully as mudcreepers (*Cerithideopsis largillierti* and *Cerithideopsilla cingulata*) and treecreepers (*Cerithidea anticipata* and *Cerithidea reidi*). In other areas of Australia, as elsewhere in the world where they occur, members of the family Potamididae are variously known as mudsnails, mudcreepers, mudwhelks, swamp-ceriths, horn snails, tree-creepers or creepers, and therefore their common names do not distinguish them from the larger species of other families (Cerithiidae, Batillariidae) in the superfamily Cerithioidea, to which they all belong.

The Potamidadae has only been separated from another family of cerithioideans, the Batillariidae, for the past 22 years (Houbrick 1991). This separation is based on two unusual anatomical features (the long style sac and the lack of an oesophogeal gland) and molecular evidence (Reid *et al.* 2008), not shell appearance. Potamidids are different from batillariids, and indeed all other members of the Cerithioidea, by having small mantle papillae and a small feeding organ (radula) (in fact an incredibly tiny radula in *Telescopium telescopium*) with a narrow basal plate on the central tooth, by different sperm structure, and by having a different complement of proteins. The head-foot of potamidids has an extremely long, extensible, often broad snout that has, on either side, a cephalic tentacle with an eye near its base (Figure 1). The foot is moderately short and broad with a pedal gland restricted to the anterior sole margin. The mantle edge is almost smooth and has a light-sensitive pit (a pallial eye) on the underside of the inhalant siphon. The pallial eye in *Telescopium* and *Cerithidea* is highly developed and contains a lens. The gill is relatively small and reduced to a series of fine ridges in *Telescopium*. The oesophagus and the salivary glands pass through the central nerve ring (except in *Terebralia semistriata*, where the salivary glands lie outside the nerve ring). The stomach is very large and superficially resembles that of a bivalve because it has a long sac off to one side containing a solid rod of concentrated digestive enzymes (a crystalline style). The sexes are separate. Males lack a penis and instead bundle their sperm into flower-like packages

Figure 1. An adult Lesser Longbum *Terebralia palustris* has extended its head-foot from its shell and is rasping a fallen mangrove leaf, Ludmilla Creek, Darwin Harbour. (Neil Wright)

(spermatophores); those of *Terebralia sulcata* are by far the most elaborate of any cerithioidean. Females have a well-developed, elongate ovipositor on the right side of the foot (that could be mistaken for a penis!). The spawn consists of numerous eggs laid in gelatinous strings. The young hatch as free-swimming larvae that feed on phytoplankton (Healy & Wells 1998) and Houbrick (1991) inferred a long duration for the larvae in the plankton.

Potamidids are detritivores, sweeping up fine algae and detritus with a radula that emerges at the end of the long, flexible proboscis. *Terebralia palustris* is unique in changing the shape of its teeth prior to maturation allowing it to switch its diet from detritus as a juvenile to rasping freshly fallen mangrove leaves as an adult. This adult diet brings it into competition with mangrove-dwelling sesarmid crabs (Salgado-Kent & McGuinness 2008). Interestingly, populations of *T. palustris* occur in southeastern Arabia without mangrove leaves, and even survive in sheltered habitats elsewhere without any mangrove trees (Feulner 2000; Reid *et al.* 2008), so presumably these individuals must subsist on detritus for their entire life.

Despite relatively good published information about the anatomy of potamidids, I have been very surprised by how much remains to be discovered about the functional morphology, behaviour, physiology and ecology of these common molluscs. For example, we do not know what triggers sexual maturation or spawning, how long the larvae remain in the plankton, or what induces them to settle out of the plankton. Importantly, no research has been conducted on growth rates, longevity

of adults, or resilience to harvesting of the edible species (Willan & Dredge 2004). Buckworth (1995) prepared a draft strategy for management of such 'data-deficient' fisheries using modelling based on *Telescopium telescopium*.

What is very clear though is that potamidids have a very close and very long asociation with mangroves (Glaubrecht 1996), appearing to depend on the trees for shelter, as a substrate, for food and for protection from predators (Reid *et al.* 2008). The Potamididae, in addition to one family of bivalves, the Glauconomidae (R.C. Willan, unpubl.), exists exclusively among mangroves and their suite of tidal habitats (Reid *et al.* 2008). As demonstrated by a molecular phylogenetic analysis [incorporating material from Darwin Harbour that I provided] in combination with a survey of fossil specimens, the oldest modern genera (*Terebralia* and *Cerithideopsis*) first appeared in the Tethyan realm in the Mid-Eocene shortly after the origin of mangrove trees (Reid *et al.* 2008). Modern potamidids represent a single adaptive radiation that diversified in this newly created mangrove environment (Reid *et al.* 2008). Even the specialised tree-climbing taxa are mangrove obligates, and so are part of this radiation. Only those potamidid species of the genus *Cerithideopsilla* that have secondarily lost their association with mangroves, have been able to colonise temperate coastlines where mangroves do not occur.

Aboriginal people in coastal nothern Australia consume only two species of longbum – *Telescopium telescopium* (regularly) and *Terebralia palustris* (less often). However, longbums were never a dietary staple, as were bivalves (Meehan 1992). This may be because longbums have a very low protein content (Meehan 1992). Furthermore, it is said their somewhat peppery taste increases the desire for drinking (Poutiers 1998). In Asia, as elsewhere in Australia, longbums are consumed after light roasting, or steaming or boiling. Also in Asia, longbums and other mudcreepers are sometimes used as bait (Meehan 1992) and the shells (of the larger, thicker species) are utilised for making lime (Poutiers 1998).

Dichotomous key to potamidid snails of northern Australia

The following dichotomous key is based on easily visible external shell characters. This key relates to 'typical' adult shells, so atypical shells (i.e., those that have been eroded by the naturally acidic sediments they inhabit) and juveniles may not always key out correctly. The key contains prompts such as "look carefully" at difficult junctions to help make the correct choice. Additional information that can be helpful in making the right choice is given in square brackets. It will still be difficult on some occasions to distinguish between some shells of the three species of *Terebralia* and to distinguish *Cerithideopsilla cingulata* from *Cerithium coralium*, particularly when dealing with worn or immature shells. A representative shell of a Lesser Longbum *Terebralia sulcata* is illustrated to explain the features used in the dichotomous key (Figure 2). To support this key, shells of all the species are shown in Figures 3–11. I have selected these shells as being 'typical' of their species.

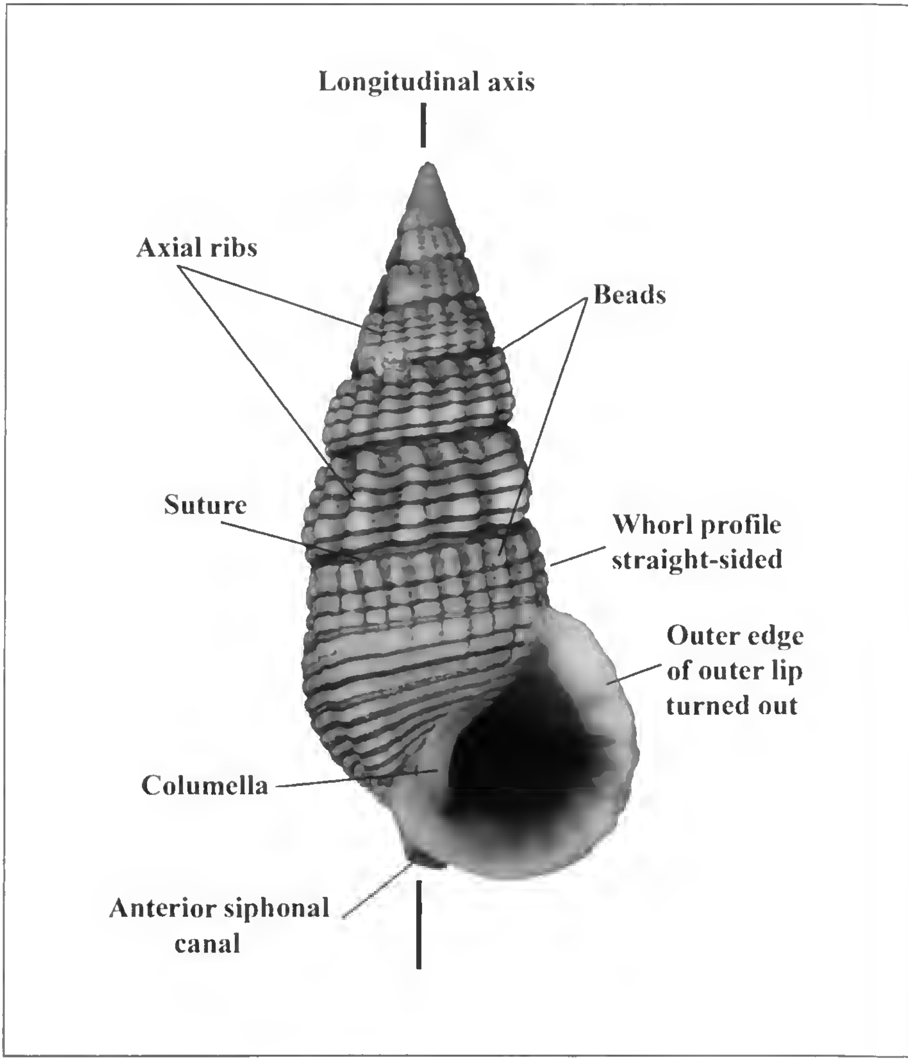


Figure 2. Ventral view of a shell of Lesser Longbum *Terebralia sulcata* to illustrate the characters mentioned in the dichotomous key. (Régis Martin)

Key to potamidid snails of northern Australia

1a. Fold present on columella of shell .... *Telescopium telescopium*

1b. No fold on columella of shell 2

2a. No ribs aligned with longitudinal axis of shell (axial ribs); maximum size of shell less than 15 mm... *Cerithideopsilla cingulata*

2b. Ribs aligned with longitudinal axis of shell present at least towards apex of shell [look carefully]; maximum size of shell greater than 15 mm 3

3a. Shell surface lacks beads (in rows or otherwise) [but surface ornamentation may include axial ribs].. 4

3b. Ornamentation on surface of shell includes rows of beads [may overlay axial ribs] 6

4a. Whorls very rounded (convex) in profile; strong axial ribs consistently present from apex to at least penultimate whorl .... *Cerithideopsis largillierti*

4b. Whorls straight-sided; weak axial ribbing, if present, only on apical third of shell and/or on body whorl 5

5a. Suture wavy [due to row of beads immediately below it]; adult shell with open (spout-like) anterior siphonal canal.. *Terebralia palustris*

5b. Suture straight; adult shell with closed (circular) anterior siphonal canal .... *Terebralia semistriata*

6a. Outer edge of outer lip strongly crinkled at margin, not turned out; maximum length of adult shell less than 28 mm.. *Cerithium coralium*

6b. Outer edge of outer lip smooth at margin, turned out; maximum length of adult shell greater than 28 mm 7

7a. Columellar wall concave; body whorl evenly rounded [apex typically present and shell relatively thick] .... *Terebralia sulcata*

7b. Columellar wall vertical (i.e., aligned with longitudinal axis of shell); body whorl squared off basally [apex typically broken off and shell thin] 8

8a. Axial ribs narrow (i.e., the majority separated by interspaces at least twice their width); maximum length of adult shell less than 40 mm .... *Cerithidea anticipata*

8b. Axial ribs broad (i.e., roughly equal in width to interspaces); maximum length of adult shell greater than 40 mm .... *Cerithidea reidi*

Comments on individual species

Longbum *Telescopium telescopium* (Figure 3)

The 'true' Longbum grows to about 100 mm shell length. *Telescopium telescopium* is the only member of the family to have a fold on the columella and it is further distinguished by its very thick shell, aperture tangential (perpendicular) to the shell's longitudinal axis, straight-sided whorls and even sculpture of small spiral cords. *Telescopium telescopium* lives on the ground in the middle section of mangrove forests or mid-tidal flats. Animals are shy to any movement and quickly retreat into their shells whenever approached (Houbrick 1991). Animals are only active when exposed by the tide. Interestingly, in Indonesia *T. telescopium* lives in a similar zone to northern Australia, but in mud so soft that it is nearly liquid. In these substrates, animals burrow into the mud as the incoming tide covers them, taking a semi-vertical position just below the surface (Budiman 1988). Aspects of the ecology of *T. telescopium* in northern Australia have been investigated by Lasiak and Dye (1986) and Wells (1986). The highest densities of *T. telescopium* have been recorded in the mid-tidal flat of mangrove forests in Darwin Harbour (Metcalfe 2007) where, in association with *Terebralia semistriata*, they are highly abundant on the shaded mud surface beneath the dense *Ceriops* canopy. *Telescopium telescopium* has an extensive distributional range throughout the tropical Indo-west Pacific Ocean. On the Australian continent it extends from Onslow in central Western Australia, around the northern coast to Bowen in central Queensland. *Telescopium telescopium* is the only species of the family that is regularly consumed by Aborigines.

Lesser Longbum *Terebralia palustris* (Figure 4)

This species grows to a maximum shell length of 120 mm, though Loch (1987) recorded an exceptionally large specimen from Arnhem Land with a shell length of 190 mm. *Terebralia palustris* is characterised by the wavy suture, strong varices, and adult shell with an open (spout-like) anterior siphonal canal. *Terebralia palustris* lives on the ground in the hinterland margin and mid-tidal flat of the mangrove forest, and also occasionally on the banks of tidal creeks where the substrate is relatively well consolidated (Wells 1980). It is the only species of the family to switch its diet as it grows; juveniles eat detritus like all other potamidids, but as they become adult they start to consume fallen mangrove leaves. This change of diet (trophic dimorphism) corresponds to a change in the shape of the teeth in the radula. *Terebralia palustris* has a very extensive distributional range throughout the tropical and warm-temperate Indo-Pacific Ocean. On the Australian continent it extends from Shark Bay in central Western Australia, around the northern coast to Townsville in northern Queensland. *Terebralia palustris* is sometimes collected and consumed by Aborigines along with *Telescopium telescopium* but as it tastes much more peppery than *Telescopium telescopium*, particularly at some times of the year, so it is often discarded live at the site of consumption on land where it eventually dies from desiccation (R.C. Willan, unpubl.).

Lesser Longbum *Terebralia semistriata* (Figure 5)

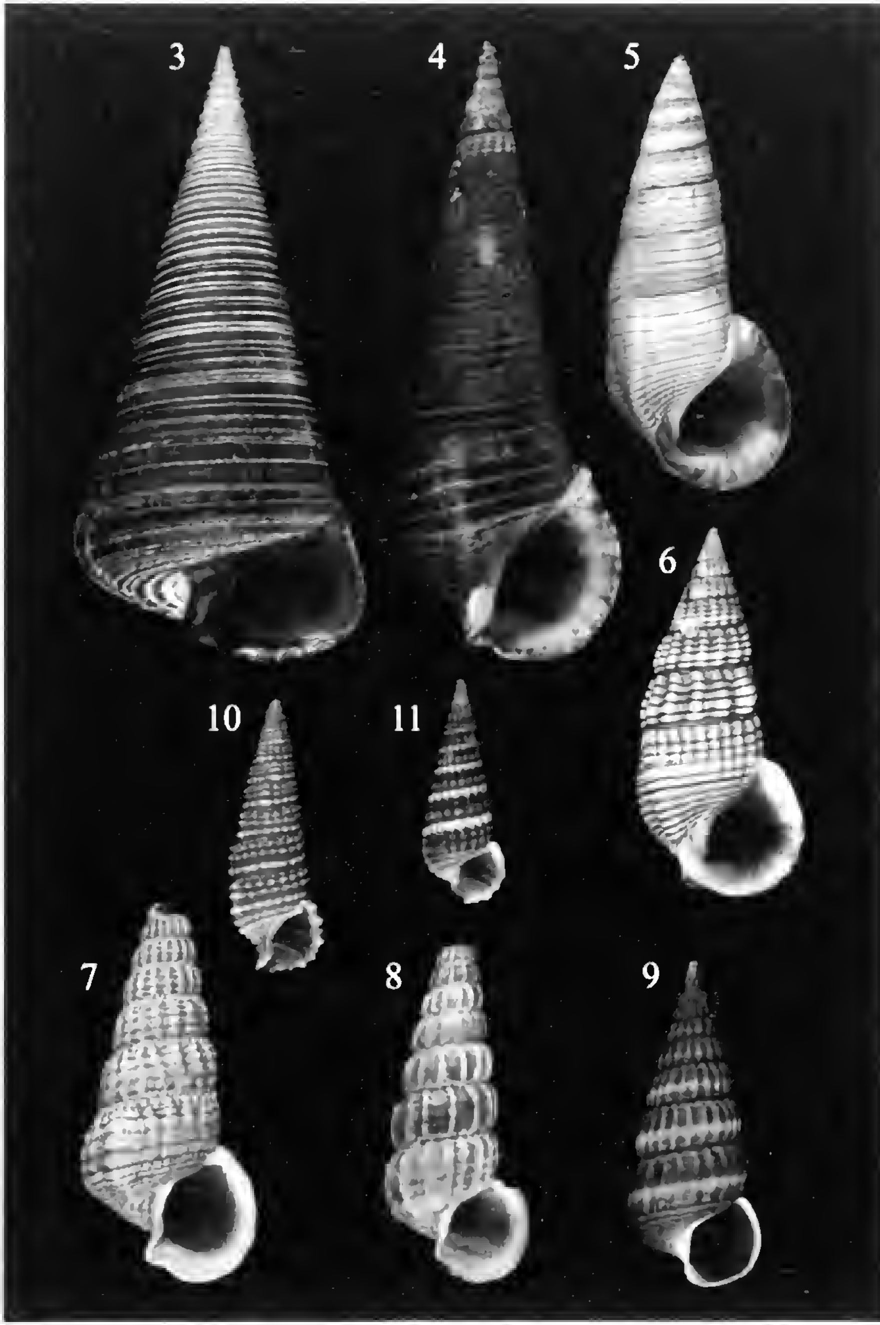
This species, which grows to about 75 mm shell length, is characterised by the expansion of the outer lip anteriorly in adults to close the anterior siphonal canal from a spout into a circular hole, straight-sided whorls, broad flattened spiral cords, and straight suture. Juveniles are particularly difficult to separate from those of *T. sulcata*. Two features that often assist correct identification are the possession by juvenile *T. semistriata* of a relatively thicker shell and broad dark spiral colour bands. Like *Telescopium telescopium*, *Terebralia semistriata* lives on the ground in the middle section of mangrove forests. In Darwin Harbour it is characteristically very numerous in the *Ceriops*-dominated mid-tidal flat, but only rarely found in the hinterland margin and tidal creek habitats. *Terebralia semistriata* is almost restricted to northern Australia with a range from North West Cape in central Western Australia, around the northern coast, to Keppel Bay in central Queensland. There is also a population at Merauke in West Papua. *Terebralia semistriata*, along with *Terebralia palustris*, is sometimes collected by 'novice' Aborigines in conjunction with the desired *Telescopium telescopium*, but *Terebralia semistriata* is highly peppery and is always discarded at the eating place (R.C. Willan, unpubl.).

Lesser Longbum *Terebralia sulcata* (Figure 6)

This, the smallest species of *Terebralia*, which only grows to about 60 mm shell length (but 50 mm is more usual), is characterised by the expansion of the outer lip anteriorly in adults to close the anterior siphonal canal from a spout into a circular hole, moderately convex whorls, straight suture, and strongly beaded spiral cords where they intersect the axial ribs; the resulting strong sculpture is notable and resembles weaving on a basket. The aperture and the body whorl are much-expanded in proportion to the remainder of the shell. The topmost whorls of the shell are often naturally broken off (decollated). *Terebralia sulcata* lives on firm ground in the lower intertidal section of mangrove forests, most often amongst the densest tangle of prop roots of *Rhizophora stylosa* or the pneumatophores of *Sonneratia alba* and *Avicennia marina*. Individuals often climb onto *Rhizophora* roots. *Terebralia sulcata* has a very extensive distributional range throughout the tropical and warm-temperate Indo-Pacific Ocean. On the Australian continent it extends from Shark Bay, central Western Australia, around the northern coast, to Torres Strait. *Terebralia sulcata* is never consumed by Aborigines.

Reid's Treecreeper *Cerithidea reidi* (Figure 7)

This species, which grows to about 60 mm shell length, is characterised by its thin shell and broad axial ribs that are strongly beaded (the strongest row of beads is immediately below the suture), and its purple-brown aperture. The apical part of the shell of adults is always naturally broken off (decollated), an adaptation to reduce the weight of the shell. *Cerithidea reidi* lives on the hinerland margin of mangrove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Figures 3–11. Representative shells of Potamididae (longbums, treecreepers and mudcreepers) plus the Mudflat-dwelling Creeper (Cerithiidae) from northern Australia. All specimens are from the mollusc collection at the Museum and Art Gallery of the Northern Territory: **3.** Longbum *Telescopium telescopium*, 82.7 mm; **4.** Lesser Longbum *Terebralia palustris*, 119.4 mm; **5.** Lesser Longbum *Terebralia semistriata*, 72.8 mm; **6.** Lesser Longbum *Terebralia sulcata*, 48.8 mm; **7.** Reid's Treecreeper *Cerithidea reidi*, 53.6 mm; **8.** Obtuse Treecreeper *Cerithidea anticipata*, 36.9 mm; **9.** Largilliert's Mudcreeper *Cerithideopsis largillierti*, 34.1 mm; **10.** Mudflat-dwelling Creeper *Cerithium coralium*, 26.6 mm; **11.** Banded Mudcreeper *Cerithideopsilla cingulata*, 13.1 mm. (Régis Martin)

forests where it climbs the trunks of (several species of) mangrove trees. *Cerithidea reidi* is the only Australian endemic species in the family with a range restricted to Western Australia, from North West Cape along the western coast to Admiralty Gulf in the Kimberley region. *Cerithidea reidi* is never consumed by Aborigines.

Obtuse Treecreeper *Cerithidea anticipata* (Figure 8)

This species, which was called *Cerithidea obtusa* in the older Australian literature, grows to about 40 mm shell length. It is characterised by its thin shell and narrow axial ribs that are weakly beaded. The apical part of the shell is always naturally broken off (decollated), an adaptation to reduce the weight of the shell. The absence of an apex gives the shell a somewhat obtuse appearance. *Cerithidea anticipata* lives in the hinterland margin and the mid-tidal flat of mangrove forests and also in saltmarsh environments, often occurring in extremely high densities amongst the foliage of the canopy (Metcalfe 2007). *Cerithidea anticipata* is rarely found on the ground, mainly foraging low on trunks of (several species of) mangrove when conditions are suitably moist, but it remains quiescent in the upper canopy during the drier months (McGuinness 1994). When resting on tree trunks, *C. anticipata* attaches by dried mucus, with only a small part of the flanged outer lip in contact with the trunk. Individuals cluster preferentially on the more shaded side of the trunk around the fringe of clearings. McGuinness (1994) showed experimentally that individuals climb higher and are less active during neap tides than during spring tides. This observation led McGuinness (1994) to conclude that this species [and, by extrapolation, other treecreepers] climbs primarily to avoid physiological stress during neap tides, rather than to avoid subtidal predators during spring tides. *Cerithidea anticipata* has an extensive distributional range throughout the tropical western Pacific Ocean. On the Australian mainland it is found from Admiralty Gulf in northern Western Australia, around the northern coast to Moreton Bay in southern Queensland. *Cerithidea anticipata* is never consumed by Aborigines.

Largilliert's Mudcreeper *Cerithideopsis largillierti* (Figure 9)

This species, which grows to about 35 mm shell length but is often smaller, is characterised by its relatively thin shell, very convex whorls and strong smooth axial ribs. Its colouration is variable, and it can be banded or uniformly chestnut-brown. *Cerithideopsis largillierti* lives on the ground in the middle to lower-tidal sections of mangrove forests where the mud is softest and it always remains in shallow pools when the tide is out. *Cerithideopsis largillierti* has an extensive distributional range throughout the tropical western Pacific Ocean. On the Australian maninland it ranges from the Kimberley region of northern Western Australia, around the northern coast to northern Queensland. *Cerithideopsis largillierti* is never consumed by Aborigines.

Banded Mudcreeper *Cerithideopsilla cingulata* (Figure 11)

This species (more probably a complex of as many as 14 cryptic species) (D. Reid, pers. comm.), which grows to about 15 mm shell length but is often 10 mm or less, is the smallest member of the family worldwide. It is characterised by the spiral rows of beads that do not align axially, by the absence of an anterior canal, and by the expansion of the outer lip posteriorly into a flaring, wing-like process. Its colouration is variable. *Cerithideopsilla cingulata* lives on the ground in a variety of habitats and substrate types – on the hinterland margin of mangrove forests, on the margins of tidal creeks and saltmarsh and adjacent tidal flats and saltpans, and also on sheltered muddy sandflats not fringed by mangroves (R.C. Willan, unpubl.). In fact, it rarely lives amongst the mangrove trees themselves so it is actually the only member of the family Potamididae in Australia capable of existing outside mangrove forests. It can be extremely abundant where it occurs; for example Poutiers (1998) cited a density of 500 m^{-2}. *Cerithideopsilla cingulata* has an extensive distribution throughout the tropical western Pacific Ocean. On the Australian mainland, its range is from Dampier in central Western Australia, around the northern coast to Moreton Bay in southern Queensland. *Cerithideopsilla cingulata* is far too small to be consumed by Aborigines.

Mudflat-dwelling Creeper *Cerithium coralium* (Figure 10)

Though shell length in adults is highly variable (Houbrick 1992), this species can grow to a maximum of 28 mm. It is one of the few species of the extremely large family of true creepers (Cerithiidae) to live in mangrove environments (Houbrick 1992), or on any soft intertidal substrate. Houbrick (1992 p. 66) had no doubt that the presence of mangrove forests is a critical factor in its distribution. Therefore, when it occurs with juvenile longhums and/or other species of mudcreepers in these habitats it is easily confused with them. In such habitats the shells of all the cerithioidean species are usually dark brown, highly eroded, and convergent in general shape and sculpture and, as Houbrick (1992) observed, the problems of identification are compounded by the mixing of shells of different taxa between habitats by hermit crabs. *Cerithium coralium* is characterised by its tall, tapering,

dark brown shell comprising straight-sided whorls each sculptured with three aligned spiral rows of beads, the spindle-shaped aperture with a thickened parietal callus, the deep anal canal, the longish and deflected anterior canal, and by the strongly crinkled margin of the outer lip. *Cerithium coralium* can live on a wide range of intertidal estuarine habitats – from the seaward fringe of mangrove forests to the soft bare mud on sheltered shores not bordered by mangroves. Though it and *Cerithideopsilla cingulata* exist naturally at opposite zones of mangrove forests, they can occur together at the water line on very protected sloping beaches and brackish lakes. Both species are particularly common in Darwin's Lake Alexander, which is a brackish lake. *Cerithium coralium* lives in areas of high organic content and is a deposit feeder (Yipp 1980), so it competes with *Cerithideopsilla cingulata* where they occur together. Despite intensive surveys of mangrove forests over the last decade, observers have only two records of this species from a range of sites in Darwin Harbour. Both were from the seaward or *Sonneratia* zone (Metcalfe 2007, 2010). *Cerithium coralium* has a moderate distributional range throughout the tropical western Pacific Ocean centered around the continental margins and large archipelagos. On the Australian continent it ranges from Shark Bay in central Western Australia, around the northern and eastern coasts supposedly to Sydney Harbour in central New South Wales. Beechey (2012) notes that the Sydney Harbour records relate to only a few specimens collected in the nineteenth century. However, there appears to be a living population in Manly Lagoon just north of Sydney, and the species becomes more common northwards from there. *Cerithium coralium* is never consumed by Aborigines.

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Brachychiton megaphyllus, the Red-flowered Kurrajong

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Abstract

The Red-flowered Kurrajong *Brachychiton megaphyllus* is a large-leaved shrub of savanna and open forests of the north-west of the Northern Territory, Australia. It is deciduous during the tropical dry season and flowers and fruits whilst leafless. Excavation revealed a large, carrot-shaped tap-root which may enable the plant to maintain positive moisture balance whilst flowering by storing water. The Red-flowered Kurrajong raises intriguing questions about seasonality and life history in the monsoon tropics.

The Red-flowered Kurrajong *Brachychiton megaphyllus* Guymer (Malvaceae: Sterculioideae; formerly Sterculiaceae) is a common understorey shrub in open forests near Darwin. It is endemic to the Top End of the Northern Territory. Features of its biology include its few and exceptionally large leaves (Prior *et al.* 2003) that are shed late in the wet or early in the dry season (Williams *et al.* 1997; Prior *et al.* 2004), and its habit of flowering and fruiting while leafless (Figures 1–2). Near Darwin, leaves are shed in April and May (i.e. early in the dry season) and new ones appear mostly in October and November (i.e. usually after the first rains) (Prior *et al.* 2004); leaf lifespan averages 7.0 months (Prior *et al.* 2003).

Guymer (1988) described *B. megaphyllus*, separating it and several other species from *B. paradoxus*. Compared to *B. paradoxus* (BP) as he circumscribed it, *B. megaphyllus* is "readily distinguished" by: the sparse pubescence on the leaves and branchlets (BP has more and larger hairs); the larger slightly-leathery leaves (BP rarely exceeds 17 cm in length and width); and the (8-)10-30-flowered inflorescences (BP 2-10-flowered). The species occur parapatrically (adjacent with little or no overlap) across the Top End of the Northern Territory, with *B. megaphyllus* occupying the west and *B. paradoxus* the east and extending into Queensland. The dividing line lies approximately between Maningrida and Ramingining on the north coast of Arnhem Land, extending south-south-west to Barunga and Mataranka and thence south to Daly Waters (Figure 3). However, the species are often still confused

in the literature and the name *B. paradoxum* misapplied to both. For example, both Brock's (2001) description of Red-flowered Kurrajong and Wilson *et al.*'s (1990) description of vegetation types in the Northern Territory include both species under the name *B. paradoxum.*

The following morphological description draws heavily on that of Guymer (1988) but also incorporates our own observations. Around Darwin, *B. megaphyllus* is mostly a shrub to 3 m with one or more stems less than 5 cm diameter. However, in some areas such as the Victoria River District it can reach to 6 to 8 m in height and develop a trunk 10–25 cm diameter. It is sparingly branched with terminal branches that may be up to 1 cm diameter. Leaves mostly grow on terminal shoots. They are broadly ovate or almost circular and sometimes shallowly 3-lobed with a cordate (heart-shaped) base. Juvenile leaves in particular can be more than 30 cm in length by 25 cm in width. The brick-red flowers have a yellow or green base and appear in short-stalked clusters in former leaf-axils on old wood (Figure 1). They comprise a single perianth whorl, that is there are no distinct sepals and petals, the five

Figures 1–2. Red-flowered Kurrajong *Brachychiton megaphyllus*: **1.** flowers appear during the dry season when the plants are leafless; **2.** large woody fruits appear late in the dry season when the plants are leafless but may persist after new leaves are formed early in the wet season. (Don Franklin)

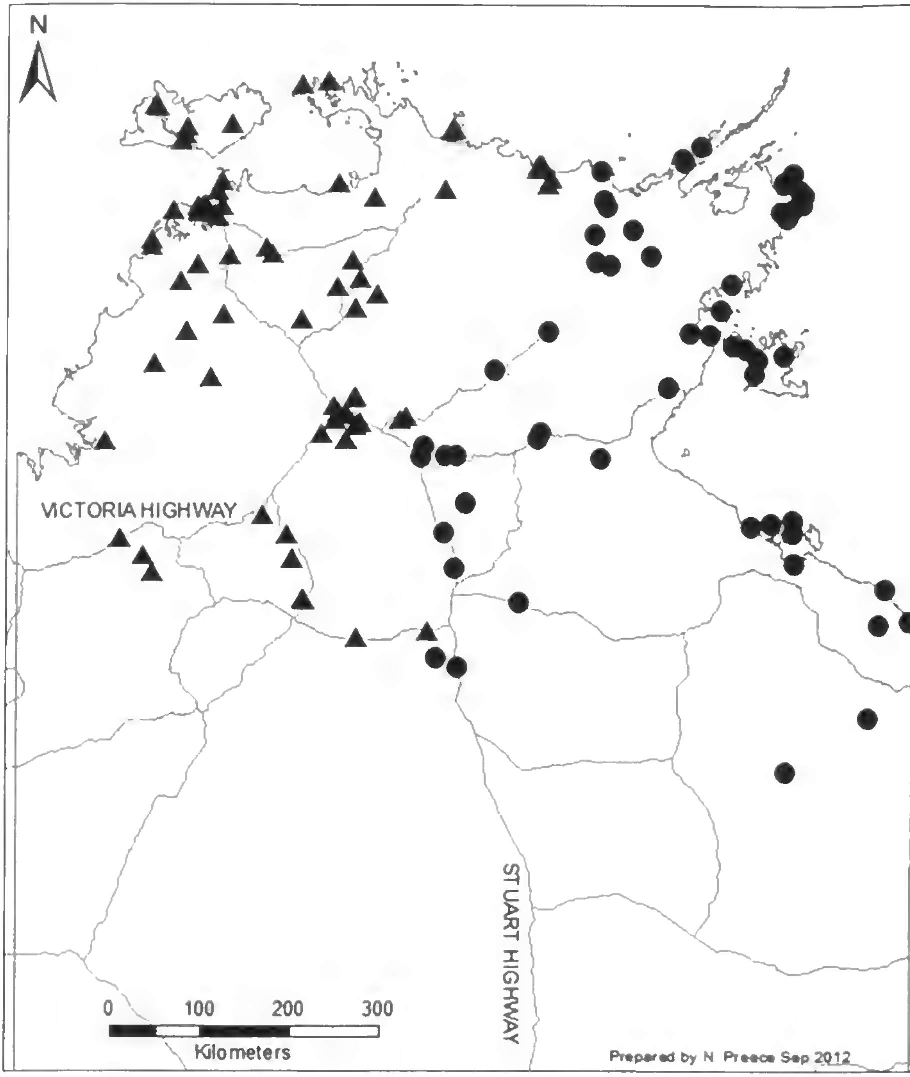


Figure 3. Distribution of *Brachychiton megaphyllus* (triangles) and of *B. paradoxus* (circles) in the Northern Territory as indicated by records from the Northern Territory Herbarium database. Grey lines represent highways.

(sometimes six) tepals being fused for 75–85% of their length to form an open, bell-shaped tube 2.5 to 5 cm diameter at the open end. Flowers are unisexual, but the sexes are similar in general appearance (Figures 4–5) and both sexes appear on the one plant (i.e. the plant is *monoecious*). The fruits are yellow-brown softly-hairy woody follicles to *c.* 10 cm long that split longitudinally and support 25 to 45 seeds each 8 to 9 mm long by 6 to 7 mm in diameter.

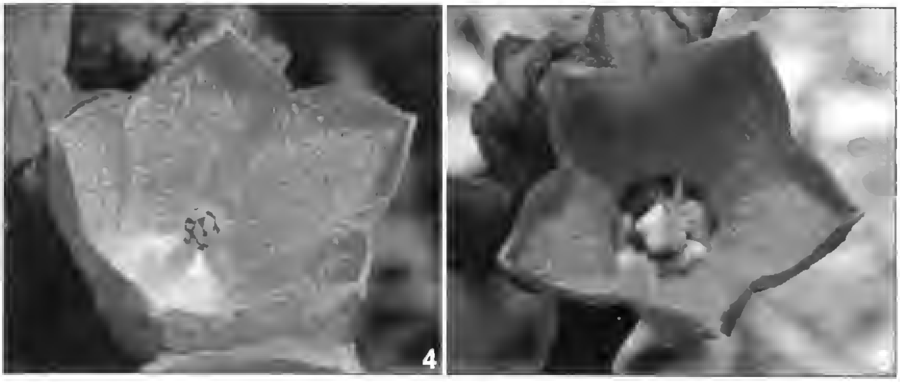
Whereas many deciduous plants of the seasonal tropics are shallow-rooted (Givnish 2002), an intriguing feature of *B. megaphyllus* is that it has a thickened, carrot-shaped tap root. Wiynjorrotj *et al.* (2005) illustrate a tap root that is c. 50 cm long and 5 cm in diameter. Our excavations show that the tap root can grow to at least 10 cm in diameter (Figure 6–7), and that there are remarkably few lateral or fine roots within 50 cm of the soil surface.

Brachychiton megaphyllus occurs in moderate to well-drained woodlands and open forests with a range of associated species and among both shrubby and predominantly grassy understoreys (Bowman & Wightman 1985; Wilson *et al.* 1990; Sharp & Bowman 2004; Brady & Noske 2010). It is often though far from invariably associated with either or both Darwin Woollybutt (*Eucalyptus miniata*) and Darwin Stringybark (*E. tetrodonta*). Though not known to fix nitrogen (Schulze *et al.* 1998), leaves have a high nitrogen content (Schmidt *et al.* 1998).

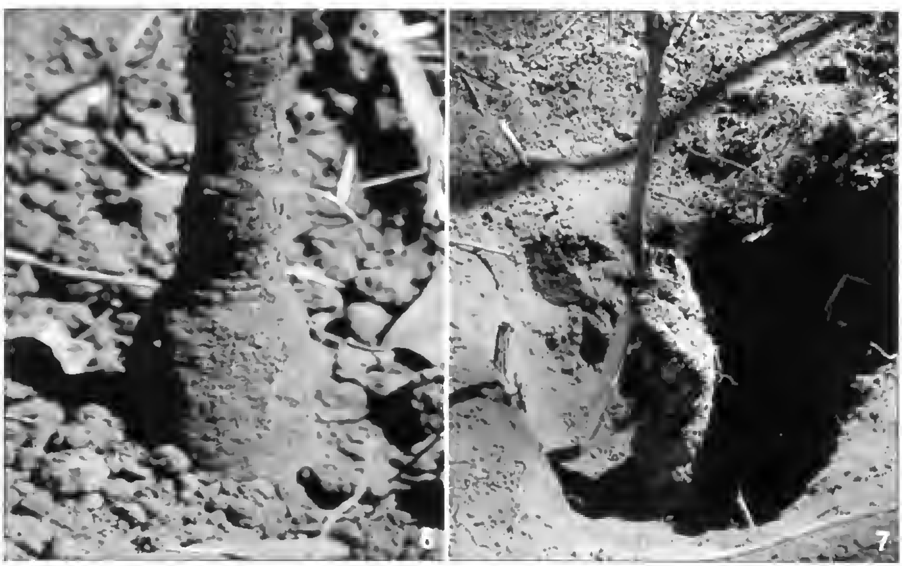
The open tubular shape of the flowers with a ring of nectaries at the inside base, along with their vivid red colour, suggests a generalised vertebrate-oriented pollination syndrome (Vickery 1992; Franklin & Noske 1999). A variety of honeyeaters, mostly smaller species, probe the flowers in evident nectarivory (Franklin & Noske 1999). Small native bees, probably *Trigona mellipes*, also visit the flowers, and they and the Brown Honeyeater *Lichmera indistincta* and Dusky Honeyeaters *Myzomela obscura* transport pollen (Alison Worsnop, pers. comm.).

Aboriginal people used *B. megaphyllus* for food and structural material and as a calendar plant (Smith *et al.* 1993; Marrfurra *et al.* 1995; Lindsay *et al.* 2001; Liddy *et al.* 2006; White *et al.* 2009). The seeds can be eaten after singeing to remove the irritant hairs, the roots can be eaten roasted or raw, and the gum is eaten raw. Bark of the species provides string and rope that can be used to tie food bundles and to make fish traps and nets. The gum can be mixed with ochre and applied to the skin for ceremonial purposes and the large leaves can be used to carry sugarbag (honey). The onset of flowering is a signal that Freshwater Crocodiles *Crocodylus johnstoni* are laying eggs.

The wide distribution and local abundance of *B. megaphyllus*, along with its tolerance of fire (Russell-Smith *et al.* 2003; Woinarski *et al.* 2004), mean that it is in no way a threatened species. Localised declines in the vicinity of Darwin seem likely to have followed clearing of Darwin Woollybutt/Darwin Stringybark open forests.



Figures 4–5. Flowers of the Red-flowered Kurrajong: **4.** Male; and **5.** Female. The five-branched stigma of the female flower is red but in some flowers it is white. (Don Franklin)



Figures 6–7. Excavated top of expanded carrot-shaped tap roots of the Red-flowered Kurrajong: **6.** A relatively young plant (Don Franklin); **7.** On what is assumed to be an old plant in which the above-ground parts have regenerated after fire (Will Duiker).

Brachychiton megaphyllus shows little or no ability to recolonise areas mined for sand or gravel (Price *et al.* 2005).

The annual cycle of *B. megaphyllus* poses intriguing questions with implications for the life histories of a range of plants in the monsoonal tropics. Leaf shed no later than early in the dry season suggests pre-emptive avoidance of desiccation rather than a response to it. Desiccated plants cannot flower and fruit; the fleshy tap root may well be used to store sufficient moisture to enable reproduction during the dry season. Janzen (1967) proposed that many plants flower during the tropical dry season to maximise resources for vegetative expansion during the wet season, as well as to optimise pollination. An alternative, or additional, explanation for the timing of flowering may be to minimise seed predation and maximise time available for seedling establishment before the next dry season, by producing seed late in the dry season. This explanation is contingent on the seed lacking strong dormancy and thus being able to germinate early in the wet season, which seems likely as in cultivation it germinates readily at any time (Yvette Brady, Greening Australia, pers. comm.). It may be no coincidence that the flowers of *B. megaphyllus* are red, a recognised colour signal for birds (Vickery 1992). Further, flowering whilst leafless may render the flowers more visible to potential pollinators (Janzen 1967). A number of plants in monsoonal Australia that flower in the dry season, when insects and fruit are often in short supply, attract a range of birds (not restricted to honeyeaters and lorikeets) as potential pollinators (Franklin 1999) and have red or orange flowers. Examples include Darwin Woollybutt, Scarlet Gum *Eucalyptus phoenicea*, Fern-leaved Grevillea *Grevillea pteridifolia* and a number of other grevilleas, and the Kapok Tree *Bombax ceiba* which also flowers whilst leafless. It would be interesting to know whether the very large but short-lived leaves of *B. megaphyllus* provide a high benefit:cost ratio to the plant per unit time. Leaves have low leaf mass per unit area (Prior *et al.* 2003), indeed suggesting that they are produced at low cost per unit area of photosynthetic capacity.

Acknowledgements

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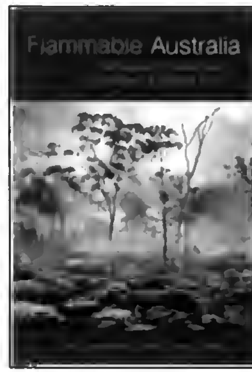
Book Review

Flammable Australia. Fire Regimes, Biodiversity and Ecosystems in a Changing World.

By R.A. Bradstock, A.M. Gill and R.J. Williams (eds). CSIRO Publishing, Collingwood, Melbourne. 2012; 333 pp; paperback. ISBN: 9780643104822. Price A$79.95.



Fire is an ecological and physical factor of great relevance in monsoonal northern Australia, and there is ample evidence of fire on an almost daily basis in the dry season. It was therefore with some sense of expectation that I read the 2012 edition of *Flammable Australia*. This is the most recent incarnation of an assemblage of the latest information from fire experts from around Australia. Previous editions were published in 2002 (*Flammable Australia: the Fire Regimes and Biodiversity of a Continent* eds R.A. Bradstock, J.E. Williams and A.M. Gill. Cambridge University Press, Cambridge) and before that in 1981 (*Fire and the Australian Biota* eds A.M. Gill, R.H. Groves and I.R. Noble. Australian Academy of Science, Canberra). The Charles Darwin University library copy of the chapter by Williams *et al.* (Fire regimes and biodiversity in the savannas of northern Australia) in the 2002 edition is well-thumbed and evidently widely read, giving some indication of the interest in fire ecology in this part of the world.

In a country as large as Australia, a major issue is how to deal with diverse fire regimes that are affected by contrasting climatic conditions in different parts of the continent. Parts of the book are thus of only partial relevance to northern Australia. For example, Chapter 3 by Sullivan *et al.* ('Fuel, fire weather and fire behaviour in Australian ecosystems') provides an introduction to fire weather and the factors that initiate and promote fire (temperature, humidity, wind, fuels, etc.). However, I found it slightly frustrating as there was no specific reference to savannas, these regions being subsumed under the general heading of 'grasslands'. Sullivan *et al.* also examine climate patterns and suggest that the fire season moves south as the year progresses, so that in northern Australia the peak fire season occurs during 'winter and spring' (= dry season) whereas in southern Australia it peaks in summer. In Chapter 4 on remote sensing, we learn that northern Australia has the highest fire frequency on the continent, with some areas in the Top End burnt every year. Several other chapters deal with the prehistory of fire, global change, carbon, and arid zone and southern biomes, and all are supplied with an extensive list of references.

Although the book includes 15 chapters, my focus in this review is on those chapters that are most relevant to monsoonal northern Australia. These are Chapter 2

by David Bowman *et al.* ('Fire regimes and the evolution of the Australian biota'), Chapter 8 by Rod Fensham ('Fire regimes and biodiversity in the savannas of northern Australia') and Chapter 14 by Garry Cook *et al.* ('A revolution in northern Australian fire management: recognition of Indigenous knowledge, practice and management').

Amongst other matters, Bowman *et al.* (Chapter 2) discuss the 'Mutch hypothesis', the theory that fire and plants in Australia have coevolved, so that we have many fire-tolerant and often highly flammable plants. This is the widely held and pervasive idea that the Australian bush is somehow 'meant to burn'. However, as these authors point out, "it is difficult to confidently attribute plant traits that promote flammability as fire adaptations", and "there are no unambiguous plant features in the fossil record that can be interpreted as fire-related adaptations". The authors discuss the timing of the evolution of epicormic buds (sprouts that emerge from aerial stems or branches after fire) in the Myrtaceae. They also dispel the notion that indigenous burning caused the evolution of fire-adapted species—although from a human perspective people colonised Australia a very long time ago, from an evolutionary and biogeographical standpoint this is a very short history indeed.

The tropical savannas of northern Australia extend across the Kimberley, Top End and northern Queensland. Fensham (Chapter 8) discusses the influence of fire on rainforest-savanna boundaries and examines the conditions that are conducive to the development of rainforest and the role of lightning. The tree recruitment bottleneck (the notion that few saplings are able to attain sufficient height and thus mature in areas that are regularly burnt) is another hypothesis that is examined, but the issue is more complicated than it first appears. Research is continuing on how trees in the savannas might escape the bottleneck. This may become more difficult as fuel loads and fire intensity are increasing significantly with the invasion of gamba and mission grass, which appear to be irreversibly simplifying the savannas.

Cook *et al.* (Chapter 14) discuss indigenous fire management and the breakdown of traditional burning practices with European colonisation. These themes are explored in greater detail in another recently published book by Russell-Smith *et al.* (2009): *Culture, Ecology and Economy of Fire Management in North Australian Savannas: Rekindling the Wurrk Tradition.* As we consider the ongoing issue of fire in the landscape we are left wondering what type of fire regimes we should adopt in the future. This is problematic given the addition of climate change, habitat fragmentation, changing land use, invasive animals and plants, and the mystery of mammal declines to the equation. Humans are now (and have been for some time) the principal fire managers in the landscapes of northern Australia. As was noted by Williams *et al.* in the previous edition of *Flammable Australia*, "ignition in the savannas is overwhelmingly due to human activity". Bowman *et al.* contrasts European fire management with the patchwork created by Aboriginal burning, and the infrequent lightning-initiated fires before humans arrived. There will undoubtedly be further

alterations to the ecology of natural areas before we find a workable compromise, but hopefully this will occur before we do irreparable harm. Regardless of our attitudes to fire and what type of fire regime we would prefer, it is important that we give some thought as to why we are burning (as Aboriginal people traditionally did) *before* we burn. Hopefully this book will go some way to helping us make informed decisions about dealing with this vital component of Australian ecosystems.

In summary, the book is generally well presented with many figures (including some in colour) and tables, and is moderately priced for a technical book of this sort. The book will be of interest to researchers and environmental scientists, and portions of the text will appeal to the general reader of natural history.

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